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MISSILE TEST CELL DESIGN LOAD AND SAFE SITING CRITERIA

by

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1.0 INTRODUCTION

1.1 Background

The reliability of today's highly sophisticated weapons systems is dependent on simulation tests. These power-on, all-up tests are required prior to delivery to the fleet and periodically during the life of the missile. The tests must be conducted in hardened missile test cells (MTCs) to prevent communication of an accidental explosion to ordnance outside the cell and to limit leakage pressures in adjacent occupied areas to less than 2.3 psi.

1.2 Problem

Operational requirements make it highly desirable to locate the MTCs directly adjacent to the Assembly Building work bay. In most cases, the Assembly Building is an existing unhardened facility with lightweight metal roofing and walls. To locate the MTC nearby the Assembly Building, the new MTC must be designed to limit the effects of an accidental explosion to less than 2.3 psi on the unhardened building. At the desired short separation distances, and with the present technology, the MTC would be required to almost completely contain the explosion and the resulting long duration gas pressure loads. The excessive cost of a complete containment test cell has made it necessary to develop new concepts for reducing the effects of a contained explosion.

1.3 Potential Solution

Recent tests conducted by the Terminal Effects Research and Analysis Group (TERA) of the New Mexico Institute of Mining and Technology, Socorro, NM, for the Naval Civil Engineering Laboratory (NCEL) and the Naval Surface Weapons Center (NSWC) have indicated that vented areas with frangible surfaces (i.e., a surface that is designed to fail in an explosion and vent the internal gas pressures) reduce the shock loads outside a containment cell. The reduction has been so dramatic that it should be possible to design a frangible panel with sufficient area and mass to adequately vent gas pressures while greatly reducing external shock pressures. The frangible panel must remain in place long enough to reflect shock waves back into the containment cell, but it must also vent the gas pressures quickly enough to keep the gas impulse inside the MTC to a manageable level.

1.4 Purpose

In December 1985, NCEL conducted tests at TERA to determine the blast environment inside and outside a scale model missile test cell. The tests are part of a program to develop Naval Facilities Engineering Command (NAVFAC) standards for missile test cell designs that meet operational requirements of the Naval Sea Systems Command (NAVSEA) and the Naval Air Systems Command (NAVAIR). Test data are presented and used to develop design load and siting requirements for NAVFAC MTCs.

2.0 TEST PROGRAM

The test structure was a 1:2.6 scale model, reinforced concrete, arch-shaped "horseshoe" structure. Dimensions are shown in Figure 1. By volume, the test structure is a 1:2.54 scale model of a rectangular NAVFAC Type I MTC. The important constant parameters were the vent area, $A = 32\ ft^2$, and the volume, $V = 920\ ft^3$. The scaled vent area was $A/V^{2/3} = 0.338$. Scaled vent areas greater than this would result in greater

pressures and impulses outside the MTC, while a smaller scaled vent area would reduce the blast environment outside the MTC. The values of fixed parameters in the test structure are as follows:

Parameter	Test Structure
Internal Volume, V (ft^3)	920
Vent Area, A (ft^2)	32
Scaled Vent Area, $A/V^{2/3}$	0.338
Floor Width, L_S (ft)	9.72
Floor Length, L_L (ft)	15.42
L_S/L_L	0.63
Initial Vent Area, A_o (ft^2)	
No Vent Cover (A_o = A)	32
With Vent Cover	0.442
Scaled Initial Vent Area, $A_o/V^{2/3}$	
No Vent Cover (A_o = A)	0.338
With Vent Cover	0.0047

Variable parameters in the test program included the TNT equivalent explosive weight, W (pounds), the vent cover weight, w (psf), and the recess of the vent cover, x (feet). The scaled parameters using these variables are the scaled distance ($Z = R/W^{1/3}$), the charge density (W/V), the scaled cover weight ($\bar{w} = w/W^{1/3}$), and the scaled cover recess ($\bar{x} = x/W^{1/3}$). The range of parameters in the test program were:

Parameter	Range of Parameter Values for Model Test Structure
Explosive Weight, W (lb TNT)	4.52 to 40.7
Scaled Weight of Vent Cover, $w/W^{1/3}$ ($psf/lb^{1/3}$)	0 to 40.6
Scaled Recess of Vent Cover, $x/W^{1/3}$ ($ft/lb^{1/3}$)	0 to 0.88

All vent covers included a 9-inch-diameter ($A_o = 0.442$ ft^2; $A_o/V^{2/3} = 0.0047$) cutout to account for uncovered openings in the MTC cover.

Table 1 summarizes the test program and the variables in each test. The arch cross section should not be a factor in applying the test results to rectangular structures provided the aspect ratio of the floor is close to that of the model.

3.0 TEST RESULTS

3.1 External Loads

The incident blast environment outside the MTC was measured at the ground locations shown in Figure 2. Gages are designated by a letter code for direction ("F" = Front; "S" = Side; "D" = Diagonal; "B" = Back) and a number code for range (the number corresponds to one-tenth the range in feet: R/10). For example, the gage designation F8 indicates a gage to the front of the MTC at a range of 80 feet.

Digitized data results are summarized in Tables 2 through 8. These tables show peak pressures and scaled impulses versus gage location and test variables (e.g., $\bar{w}$ and $\bar{x}$). Each table is for a constant W and W/V. All tests used a vent area of 32 ft^2 but varied the mass and recess of the vent cover.

Two pressure-time plots at gage 2 for Test 10 (without a cover) and Test 13 (with a cover) are shown in Figure 3. The two plots show the variations in pressure histories that are possible at the same location and for similar peak pressures and impulses. Use of an equivalent triangular load-time history is generally conservative and is sufficient for all the data used in this report.

The data in Tables 2 through 8 are plotted in Figures 4 through 19. Each figure includes the hemispherical surface burst curve for comparison. Figures 4 through 7 show the directional effects of the MTC on the blast environment with no vent cover ($\bar{w} = 0$). Figures 8 through 10 show the effect of charge density, W/V, on peak pressures and scaled impulses with $\bar{w} = 0$. Figures 11 through 19 show the effect of vent cover weight, w, and recess, x, on the blast environment.

The test results show that the tested MTC geometry and vent cover had the following general effects on the external blast environment compared to that from an unconfined hemispherical surface burst (the basis for NAVSEA OP-5 quantity distance relationships):

1. Front Direction - significant increase in pressure and impulse (over that of an unconfined hemispherical surface burst) without vent cover; increase in scaled impulse but no change in peak pressure with vent cover.

2. Side Direction - significant decrease in pressure and impulse without vent cover; variable effect with vent cover although usually small for $W/V > 0.015$.

3. Back Direction - very significant decrease with or without cover; the decrease with cover was less (except for heavy covers and large charge densities).

3.2 Internal Gas Pressure Loads

The internal gas pressure loads were measured by gages G1, G3, and G4 located inside the MTC (Figure 1). Digitized data results are summarized in Tables 2 through 8. The data results include peak gas pressure and scaled impulse. The scaled impulses, shown in these tables for comparison only, were scaled by the TNT equivalent weight for shock ($W = 1.13 \times$ weight of C4 explosive). Scaling by the gas pressure equivalent weight would require a variable factor as determined by the procedure in NAVFAC P-397. See Section 7.2 for determination of design gas pressure loads. The test results show that, as expected, the peak gas pressure is a function of W/V, and the scaled gas impulse, given a constant vent opening, depends on the mass of the cover, w, and its recess, x. The results show that the procedure in NAVFAC P-397 for determining gas pressure and impulse applies to MTC design. See Section 7.0 for the internal design gas pressure and shock loads.

4.0 SITING CRITERIA

For the remotely controlled testing in a MTC, NAVSEA OP-5 requires a scaled separation distance of 24 $ft/lb^{1/3}$. This is the scaled distance at which a hemispherical surface burst produces a peak incident

blast overpressure, P_{so}, of 2.3 psi. Because of the directional effects of the MTC on the external blast environment, the scaled distance to the back of the MTC where P_{so} is 2.3 psi is significantly reduced from that for a surface burst. "B" direction overpressure data are plotted in Figure 20 for tests without vent covers ($\bar{w} = 0$). An average slope of the data was determined from best fit power curves using data nearest 2.3 psi and for $0.015 \leq W/V \leq 0.045$ lb/ft$^{1/3}$. The data for W/V = 0.005 lb/ft^3 were not used because the overpressures were too low (< 0.5 psi). Data used are identified in Figure 20 by the solid symbols. The average slope was then used to derive the upper bound straight line relationships shown in Figure 20. As can be seen from the surface burst curves in Figures 4 through 19, straight line relationships (on log-log plots) are accurate for interpolation of free-field overpressure data over full cycle (factor of 10) ranges of P_{so}. The Z values corresponding to 2.3 psi from these upper bound curves are considered reasonable and safe for developing the siting criteria for points to the back of the MTC.

The upper bound Z values corresponding to P_{so} = 2.3 psi and no vent cover are plotted against W/V in Figure 21. In order to safely account for the effects of pressure reflections from vent covers, worst case Z values from all cover tests at W/V values of 0.015 and 0.045 lb/ft^3 were obtained from the test data. The following table shows Z values with and without vent covers and shows their ratio, F_r. F_r was calculated from worst case test data for W/V = 0.015 and 0.045 lb/ft^3. F_r for W/V = 0.025 lb/ft^3 (for which there were no data with vent covers) was obtained from linear interpolation between the other F_r values, and a resulting Z_r, with cover, was calculated.

W/V	Z_o	Z_r	F_r
0.015	6.45	8.0[a]	1.24
0.25	8.8	11.4[b]	1.30[c]
0.045	10.0	14.2[a]	1.42

Z_o = Z for 2.3 psi; $\bar{w} = 0$, from Figure 20

Z_r = Z for 2.3 psi; worst case for all $\bar{w}$ and $\bar{x}$

$F_r = Z_r/Z_o$

[a]From test data.
[b]Calculated from $Z_r = F_r \times Z_o$.
[c]From linear interpolation between other F_r values.

The Z_r values to limit P_{so} to 2.3 psi to the back of the MTC are plotted in Figure 21. The relationship applies to the following ranges of parameters:

$$0.015 \leq W/V \leq 0.045 \text{ lb/ft}^3$$

$$0 \leq \bar{w} \leq 40 \text{ psf/lb}^{1/3}$$

$$0 \leq \bar{x} \leq 0.88 \text{ ft/lb}^{1/3}$$

$$A/V^{2/3} < 0.35$$

$$L_S/L_L = 0.63\ (\pm 10\%)$$

where: L_S = short floor dimension

L_L = long floor dimension

and vent in short wall

For the NAVFAC Type I MTC, $W/V = 0.02$ lb/ft³, and from Figure 21, the safe Z for P_{so} = 2.3 psi to the back of the MTC is 9.7 ft/lb$^{1/3}$. With a rated capacity of 300 pounds, the safe distance to the rear is $9.7 \times 300^{1/3}$ = 65 feet measured from the outside of the vented wall.

5.0 DESIGN EXTERNAL BLAST LOADS

Measured blast loads were used to derive design blast loads in each direction outside the MTC. Results are shown in Figures 22 through 25. The design blast loads are based on data for $0.015 \le W/V \le 0.045\ lb/ft^3$. Design curves are summarized in Figure 26 for the design peak incident overpressure, P_{so}, and in Figure 27 for the design scaled incident impulse, $i_s/W^{1/3}$. The design curves apply to a MTC for the same range of parameters listed above for siting the Missile Processing Building. Note that siting criteria separation distances (Section 4.0) are expressed as a function of charge density (W/V), whereas design load relationships are conservatively based on worst case results for all parameters, including W/V.

5.1 "F" Direction

The blast loads to the front of the MTC ("F" Line in Figure 2) are enhanced by the focusing of shock waves escaping through the front wall vent. The effect is especially apparent without a vent cover. Peak overpressures, however, were essentially equal to those of a hemispherical surface burst for all tested vent covers ($9 \le \bar{w} \le 40\ psf/lb^{1/3}$ and $0 \le \bar{x} \le 0.9\ ft/lb^{1/3}$). Figure 22 shows worst case data and the upper bound peak overpressure design curves recommended for points to the front of a MTC. When a vent cover with $9 \le \bar{w} \le 40\ psf/lb^{1/3}$ is used, the P_{so} relationship for a hemispherical surface burst may be used. Scaled impulse data were also higher with no vent cover. Therefore, in Figure 23, two scaled impulse design curves are shown for two ranges of scaled cover weight ($\bar{w}$).

5.2 "S" Direction

Worst case peak overpressure and scaled impulse to the side of the MTC ("S" Line in Figure 2) are plotted in Figure 24. Peak overpressures, from all tests (with and without vent covers) are adequately described

by the hemispherical surface burst relationship. The upper bound envelope for scaled impulse, however, deviates from the surface burst relationship, at $Z < 40\ ft/lb^{1/3}$, as shown in Figure 24.

5.3 <u>"B" Direction</u>

The blast loads to the back of the MTC are less than those of a hemispherical surface burst. Worst case peak pressure and scaled impulse data are plotted in Figure 25 for tests with and without vent covers. Recommended design load curves are also shown in Figure 28 which, for all but a single point, are upper bounds on the pressure and impulse data.

5.4 <u>Design Load Summary</u>

Figures 26 and 27 summarize the design loads outside a MTC. Figure 26 presents the design peak incident overpressure, P_{so}, in the three major directions from the MTC. The range, R (ft), is measured from the outside center of the vent cover in the front wall. The mid-range curve is identical to the hemispherical surface burst relationship for P_{so} and applies to the side direction for all $\bar{w}$ and to the front direction for $9 \le \bar{w} \le 40\ psf/lb^{1/3}$. As shown by the curves, the blast environment is greatest in the front direction with $0 \le \bar{w} < 9\ psf/lb^{1/3}$ and the least in the back direction with or without a vent cover.

The scaled incident impulse design curves are shown in Figure 27. Two curves, for different ranges of $\bar{w}$, are required to show the design relationships to the front of the MTC. The relationships for the side and back directions apply with or without vent covers. The hemispherical surface burst curve is shown for comparison.

The load relationships in Figures 26 and 27 are limited to the ranges of parameters stated in the Figures and in Section 4.0 above.

6.0 INHABITED BUILDING QUANTITY-DISTANCE REQUIREMENTS

Figure 26 is used to define the inhabited building distance (IBD) in each direction from NAVFAC Type I (or similar) MTCs. The IBD is the distance corresponding to $P_{so} = 1.2$ psi. The safe distance to public traffic routes is 60% of IBD, in accordance with NAVSEA OP-5. From Figure 26 you obtain the following values for K:

K $(ft/lb^{1/3})$[a] for Inhabited Building Distance

Front[b]		Side	Back
$0 \leq \bar{w} < 9$	$9 \leq \bar{w} < 40$		
62	40	40	24

[a] Public traffic route quantity-distance requirements are 60% of IBD requirements.

[b] Fragments and debris from vent will require at least 1,250 feet within a 60-degree cone to front for inhabited buildings and 750 feet to front for public traffic routes.

7.0 DESIGN INTERNAL LOADS

The MTC must be designed to contain the design explosive weight of the Maximum Credible Event (MCE) from a warhead detonation. The reinforced concrete roof, sidewalls, and backwall must be designed to safely withstand the loads from a warhead detonation. The design loads consist of the initial shock wave loads from the explosive detonation and the long duration gas pressure loads caused by the containment of the products of detonation.

7.1 <u>Shock Loads</u>

Shock loads are determined with the computer program IMPRESS. IMPRESS, developed by Ammann and Whitney Consulting Engineers for ARRADCOM, is the basis for the internal shock loads provided in the revised NAVFAC P-397 Design Manual. The MTC geometry and envelope of

MCE locations are used to determine the critical location of the explosive. The TNT equivalent explosive weight for shock pressure is determined and a 1.2 factor of safety is applied to obtain the explosive weight:

$$W_{DESIGN} = W \times \text{TNT Equivalency} \times 1.2$$

IMPRESS or NAVFAC P-397 may be used to obtain an idealized triangular design shock load with peak pressure B_1 and duration T_1 as shown in Figure 28.

7.2 Gas Pressure Loads

Containment of the products of detonation creates a relatively low pressure and long duration gas pressure loading. NCEL has developed a computer program using theoretical and empirical methods to determine the gas pressure loading. The computer program, REDIPT, is described in a paper presented at the 21st DDESB Seminar: "Effect of Frangible Panels on Internal Gas Pressures," by J.E. Tancreto and E.S. Helseth, August 1984. The revised NAVFAC P-397 Design Manual uses data plots from REDIPT as the design internal gas pressure loads for containment structures.

The TNT equivalent explosive weight for determining gas pressures is calculated from the ratios of heats of combustion and heats of detonation as shown in NAVFAC P-397. A 1.2 factor of safety is applied when determining structural design loads. The design equivalent weight for gas pressure loads is calculated from the product of the actual explosive weight, the TNT equivalency, and the factor of safety, as in the equation given above for shock pressure design explosive weight. The design charts in NAVFAC P-397 are then used to calculate the idealized gas pressure loading with peak pressure B_2 and duration T_2 as shown in Figure 28.

7.3 Combined Total Internal Design Load

Due to the methods used in experimentally measuring gas pressure, the shock and gas pressure triangular load-histories should be merged, as shown in Figure 28, rather than added. A bilinear load function

results with a maximum pressure = B_1 at T = 0 and a duration of T_2. The intersection of the shock and gas pressure triangular load functions is at the B_i, T_i point:

$$T_i = \frac{(B_1 - B_2)\ T_1\ T_2}{(B_1\ T_2 - B_2\ T_1)}$$

$$B_i = B_1 \left(1 - \frac{T_i}{T_1}\right)$$

or

$$B_i = B_1 \left[1 - \frac{(B_1 - B_2)\ T_2}{B_1\ T_2 - B_2\ T_1}\right]$$

Table 1. MTC Test Parameters

NCEL Test No.	W (lb)	W/V (lb/ft³)	w (psf)	$\bar{w}$[a] (psf/lb$^{1/3}$)	x (ft)	$\bar{x}$[b] (ft/lb$^{1/3}$)
101	4.52	0.005	0[c]	0	0	0
2	4.52	0.005	31.25	18.90	0.0625	0.03
3	4.52	0.005	31.25	18.90	0.79	0.47
4	4.52	0.005	31.25	18.90	1.45	0.87
5	4.52	0.005	67.2	40.64	1.45	0.87
6	13.56	0.015	0	0	0	0
106	13.56	0.015	0	0	0	0
18	13.56	0.015	31.25	13.10	0.0625	0.02
19	13.56	0.015	31.25	13.10	1.66	0.69
7	13.56	0.015	47.7	20.00	0.094	0.03
8	13.56	0.015	47.7	20.00	1.05	0.44
9	13.56	0.015	91.4	38.33	2.1	0.88
109	22.6	0.025	0	0	0	0
10	40.7	0.045	0	0	0	0
11	40.7	0.045	31.25	9.08	0.0625	0.01
12	40.7	0.045	31.25	9.08	1.66	0.48
13	40.7	0.045	67.2	19.53	0.135	0.03
14	40.7	0.045	67.2	19.53	1.66	0.48
17	40.7	0.045	134	38.96	1.66	0.48

[a] $\bar{w} = w/W^{1/3}$

[b] $\bar{x} = x/W^{1/3}$

[c] Zero indicates no cover over vent opening.

Table 2. Peak Pressure ($W = 4.52$ lb; $W/V = 0.005$ lb/ft^3)

Gage	Scaled Distance, Z (ft/lb$^{1/3}$)	Peak Pressures (psi) for NCEL Test Nos.-- 101[a]	2[b]	3[c]	4[d]	5[e]
External Incident Pressures, P_{so}						
F1	6.06	43.4	11.5	9.35	21.9	18.4
F2	12.1	18.6	4.39	3.96	9.58	7.41
F3	24.2	3.92	1.17	1.1	0.85	0.63
F8	48.5	0.93	0.58	0.57	0.47	0.44
F12	72.7	0.47	0.42	0.34	0.29	0.31
S1	6.06	8.86	4.63	5.13	21.5	20.8
S2	12.1	4.14	2.55	2.48	14.3	11.1
S4	24.2	1.01	1.18	0.69	1.0	1.08
S8	48.5	0.49	0.31	0.3	0.37	0.54
D2	12.1	1.18	1.35	0.92	1.37	1.62
D4	24.2	0.44	0.73	0.41	0.53	0.57
D8	48.5	0.22	0.3	0.23	0.24	0.27
B2	12.1	0.52	0.67	0.58	0.67	0.55
B3	18.2	0.42	0.49	0.48	0.53	0.4
B4	24.2	0.25	0.3	0.4	0.33	0.28
B8	48.5	0.21	0.21	0.35	0.23	0.2
Internal Gas Pressures, P_g						
G1	f	31	41	46	49	48
G3	f	24	--	--	45	44
G4	f	26	38	41	48	47

[a] No cover.

[b] $\bar{w} = 18.9$; $\bar{x} = 0.04$.

[c] $\bar{w} = 18.9$; $\bar{x} = 0.48$.

[d] $\bar{w} = 18.9$; $\bar{x} = 0.88$.

[e] $\bar{w} = 40.6$; $\bar{x} = 0.88$.

[f] Internal gas pressure gage on wall. Distance not a factor.

Table 3. Scaled Impulse ($W = 4.52$ lb; $W/V = 0.005$ lb/ft^3)

Gage	Scaled Distance, Z (ft/lb$^{1/3}$)	Scaled Impulse (psi-ms/lb$^{1/3}$) for NCEL Test Nos.--				
		101[a]	2[b]	3[c]	4[d]	5[e]
External Incident Impulse, $i_s/W^{1/3}$						
F1	6.06	51.65	17.53	16.32	59.27	41.73
F2	12.1	26.61	7.31	9.07	31.45	30.84
F4	24.2	9.07	3.02	3.20	3.32	3.14
F8	48.5	2.96	1.63	1.75	1.66	1.69
F12	72.7	2.41	1.02	1.14	1.08	1.02
S1	6.06	7.01	7.37	9.67	36.89	30.84
S2	12.1	5.56	4.53	5.92	26.00	18.99
S4	24.2	3.08	2.54	2.47	2.29	1.69
S8	48.5	1.51	1.08	1.14	1.08	0.90
D2	12.1	2.72	3.02	2.84	2.90	2.05
D4	24.2	1.75	1.75	1.63	1.57	1.33
D8	48.5	0.96	0.96	0.90	0.90	0.78
B2	12.1	1.99	2.35	2.05	2.17	1.63
B3	18.2	1.93	2.05	2.41	2.35	2.11
B4	24.2	1.27	1.93	1.75	1.63	1.39
B8	48.5	0.84	1.08	1.02	1.02	0.78
Internal Gas Impulse, $i_g/W^{1/3}$						
G1	f	115	549	682	780	986
G3	f	191	--	--	702	898
G4	f	215	505	641	721	961

[a]No cover.

[b]$\bar{w} = 18.9$; $\bar{x} = 0.04$.

[c]$\bar{w} = 18.9$; $\bar{x} = 0.48$.

[d]$\bar{w} = 18.9$; $\bar{x} = 0.88$.

[e]$\bar{w} = 40.6$; $\bar{x} = 0.88$.

[f]Internal gas pressure gage on wall. Distance not a factor.

Table 4. Peak Pressure ($W = 13.56$ lb; $W/V = 0.015$ lb/ft^3)

Gage	Scaled Distance, Z (ft/lb$^{1/3}$)	Peak Pressures (psi) for NCEL Test Nos.-- 6[a]	106[a]	18[b]	19[c]	7[d]	8[e]	9[f]
		External Incident Pressures, P_{so}						
F1	4.19	103.7	83.9	31.9	19.9	27.1	26.4	
F2	8.38	39.5	46.5	13.3	6.43	9.07	7	
F4	16.8	8.47	9.35	3.74	3.28	2.87	3.34	4.39
F8	33.5	2.56	2.63	1.33	1.04	1.11	1.23	0.93
F12	50.3	1.45	1.55	0.75	0.63	0.69	0.65	0.68
S1	4.19	24.5	27.0	17.7	18.2	23.1	13.1	
S2	8.38	8.09	8.86	13.7	9.75	8.57	12.9	
S4	16.8	2.16	1.63	2.3	2.39	2.23	2.27	2.7
S8	33.5	0.79	0.86	1.06	1.26	0.86	1.33	0.94
D2	8.38	2.4	2.48	3.38	2.69	4.16	3.45	3.24
D4	16.8	0.84	1.0	1.54	1.57	1.48	1.7	1.6
D8	33.5	0.4	0.41	0.68	0.65	0.54	0.72	0.64
B2	8.38	1.29	1.66	1.38	1.38	2.17	1.96	1.78
B3	12.6	0.99	0.97	1.05	1.18	1.25	1.33	1.11
B4	16.8	0.78	0.65	0.96	0.97	0.98	1.01	0.77
B8	33.5	0.48	0.47	0.71	0.63	0.5	0.73	0.46
		Internal Gas Pressures, P_g						
G1	g	56	61	76	90	82	89	--
G3	g	59	56	76	85	--	75	--
G4	g	48	53	70	86	71	87	--

[a]No cover.

[b]$\bar{w} = 13.1$; $\bar{x} = 0.02$.

[c]$\bar{w} = 13.1$; $\bar{x} = 0.69$.

[d]$\bar{w} = 20$; $\bar{x} = 0.03$.

[e]$\bar{w} = 20$; $\bar{x} = 0.44$.

[f]$\bar{w} = 38.33$; $\bar{x} = 0.88$.

[g]Internal gas pressure gage on wall. Distance not a factor.

Table 5. Scaled Impulse ($W = 13.56$ lb; $W/V = 0.015$ lb/ft^3)

Gage	Scaled Distance, Z (ft/lb$^{1/3}$)	Scaled Impulse (psi-ms/lb$^{1/3}$) for NCEL Test Nos.-- 6[a]	106[a]	18[b]	19[c]	7[d]	8[e]	9[f]
External Incident Impulse, $i_s/W^{1/3}$								
F1	4.19	75.30	62.47	28.25	25.99	27.79	27.12	
F2	8.38	30.56	29.18	11.06	10.77	12.49	13.66	
F4	16.8	14.04	14.42	5.19	7.50	5.24	7.21	12.20
F8	33.5	6.24	6.07	2.68	3.22	2.59	3.27	2.68
F12	50.3	3.60	3.64	1.67	2.01	1.71	1.97	1.59
S1	4.19	9.55	10.69	17.23	15.47	16.43	16.10	
S2	8.38	7.92	8.00	11.57	13.87	13.08	12.07	
S4	16.8	3.81	3.56	4.06	3.77	4.19	4.06	3.98
S8	33.5	2.13	2.18	1.97	1.92	2.01	2.01	1.88
D2	8.38	3.56	3.31	4.94	4.19	5.11	4.73	4.73
D4	16.8	2.22	2.18	2.85	2.68	2.85	2.80	
D8	33.5	1.29	1.29	1.59	1.46	1.59	1.59	
B2	8.38	2.09	2.64	3.98	3.60	3.68	3.89	
B3	12.6	2.76	2.47	3.64	3.52	3.94	3.56	
B4	16.8	2.13	2.22	3.22	3.18	3.10	3.27	
B8	33.5	1.25	1.34	1.92	1.84	1.88	1.84	
Internal Gas Impulse, $i_g/W^{1/3}$								
G1	g	382	411	758	1006	782	1048	--
G3	g	382	361	670	946	--	933	--
G4	g	306	346	675	902	709	925	--

[a] No cover.

[b] $\bar{w} = 13.1$; $\bar{x} = 0.02$.

[c] $\bar{w} = 13.1$; $\bar{x} = 0.69$.

[d] $\bar{w} = 20$; $\bar{x} = 0.03$.

[e] $\bar{w} = 20$; $\bar{x} = 0.44$.

[f] $\bar{w} = 38.33$; $\bar{x} = 0.88$.

[g] Internal gas pressure gage on wall. Distance not a factor.

Table 6. Peak Pressure and Scaled Impulse
(W = 22.6 lb; W/V = 0.025 pcf)

Gage	Scaled Distance, Z ($ft/lb^{1/3}$)	Peak Pressure (psi)	Scaled Impulse ($psi\text{-}ms/lb^{1/3}$)
Incident Pressure, P_{so}, and Impulse, $i_s/W^{1/3}$			
F1	3.53	121.3	87.72
F2	7.07	65.7	35.33
F4	14.1	12.5	17.68
F8	28.3	3.47	7.64
F12	42.4	1.76	4.42
S1	3.53	34.6	11.67
S2	7.07	11.8	9.48
S4	14.1	2.04	4.45
S8	28.3	1.13	2.61
D2	7.07	3.5	4.06
D4	14.1	1.37	2.61
D8	28.3	0.56	1.48
B2	7.07	2.36	3.11
B3	10.6	1.92	3.32
B4	14.1	1.26	2.75
B8	28.3	0.93	1.69
Gas Pressure, P_g, and Impulse, $i_g/W^{1/3}$			
G1	b	86	532
G3	b	65	482
G4	b	66	392

[a] $\bar{w} = 0$; $\bar{x} = 0$.

[b] Internal gas pressure gage on wall. Distance not a factor.

Table 7. Peak Pressure (W = 40.7 lb; W/V = 0.045 pcf)

Gage	Scaled Distance, Z ($ft/lb^{1/3}$)	Peak Pressures (psi) for NCEL Test Nos.--					
		10[a]	11[b]	12[c]	13[d]	14[e]	17[f]
		External Incident Pressures, P_{so}					
F1	2.91	182.0	45.3	41.1	48.5	26.2	30.9
F2	5.81	72.8	18.6	13.3	14.2	15.8	16.0
F4	11.6	17.5	6.04	5.53	5.22	6.22	6.37
F8	23.3	4.36	2.54	2.51	2.19	1.91	1.45
F12	34.9	2.37	1.44	1.57	1.34	1.07	0.71
S1	2.91	40.3	26.9	30.3	22.5	25.2	14.9
S2	5.81	15.9	26.8	21.2	23.3	16.2	12.1
S4	11.6	3.03	5.11	4.24	2.56	3.91	4.26
S8	23.3	1.53	2.64	2.39	1.96	1.81	3.06
D2	5.81	5.66	8.83	5.01	5.24	5.75	3.39
D4	11.6	1.99	3.24	2.33	2.86	2.35	2.47
D8	23.3	0.97	1.32	1.18	1.2	1.33	1.07
B2	5.81	4.11	6.96	3.33	3.55	3.13	2.85
B3	8.72	2.57	3.79	1.82	2.16	2.02	1.8
B4	11.6	1.47	2.56	1.66	1.51	1.43	1.48
B8	23.3	0.98	1.73	1.35	1.13	1.74	0.93
		Internal Gas Pressures, P_g					
G1	g	103	140	172	161	218	--
G3	g	92	--	140	137	199	194
G4	g	102	148	148	146	173	185

[a] No cover.

[b] $\bar{w}$ = 9.08; $\bar{x}$ = 0.01.

[c] $\bar{w}$ = 9.08; $\bar{x}$ = 0.48.

[d] $\bar{w}$ = 67.2; $\bar{x}$ = 0.03.

[e] $\bar{w}$ = 67.2; $\bar{x}$ = 0.48.

[f] $\bar{w}$ = 134; $\bar{x}$ = 0.48.

[g] Internal gas pressure gage on wall. Distance not a factor.

Table 8. Scaled Impulse (W = 40.7 lb; W/V = 0.045 pcf)

Gage	Scaled Distance, Z ($ft/lb^{1/3}$)	Scaled Impulse ($psi\text{-}ms/lb^{1/3}$) for NCEL Test Nos.-- 10[a]	11[b]	12[c]	13[d]	14[e]	17[f]
External Incident Impulse, $i_s/W^{1/3}$							
F1	2.91		54.06	57.55	27.64		19.47
F2	5.81	35.17	17.76	17.58	12.73	16.65	10.02
F4	11.6	22.38	10.29	11.33	7.81	10.66	9.30
F8	23.3	9.09	5.52	6.01	4.47	5.43	4.53
F12	34.9	5.61	3.45	4.04	2.90	3.25	2.84
S1	2.91	12.52	14.33	14.21	15.29	13.69	13.72
S2	5.81	8.72	18.72	16.16	17.09	14.73	14.56
S4	11.6	5.05	2.47	5.43	6.39	5.98	6.25
S8	23.3	2.73	2.93	2.79	2.99	3.02	4.18
D2	5.81	10.05	6.97	6.42	6.54	5.90	5.63
D4	11.6	3.19	4.21	3.98	4.30	3.77	3.66
D8	23.3	1.91	2.20	2.18	2.44	3.54	2.12
B2	5.81	3.83	5.52	5.14	4.82	4.44	4.30
B3	8.72	4.15	5.84	4.97	4.68	4.30	4.18
B4	11.6	2.84	4.91	4.41	4.15	3.92	3.69
B8	23.3	1.94	2.79	2.67	2.50	2.41	2.32
Internal Gas Impulse, $i_g/W^{1/3}$							
G1	g	671	997	1345	1171	1581	--
G3	g	510	--	1052	996	1343	1630
G4	g	435	814	1044	1024	1364	1611

[a] No cover.

[b] $\bar{W}$ = 9.08; $\bar{x}$ = 0.01.

[c] $\bar{W}$ = 9.08; $\bar{x}$ = 0.48.

[d] $\bar{W}$ = 67.2; $\bar{x}$ = 0.03.

[e] $\bar{W}$ = 67.2; $\bar{x}$ = 0.48.

[f] $\bar{W}$ = 134; $\bar{x}$ = 0.48.

[g] Internal gas pressure gage on wall. Distance not a factor.

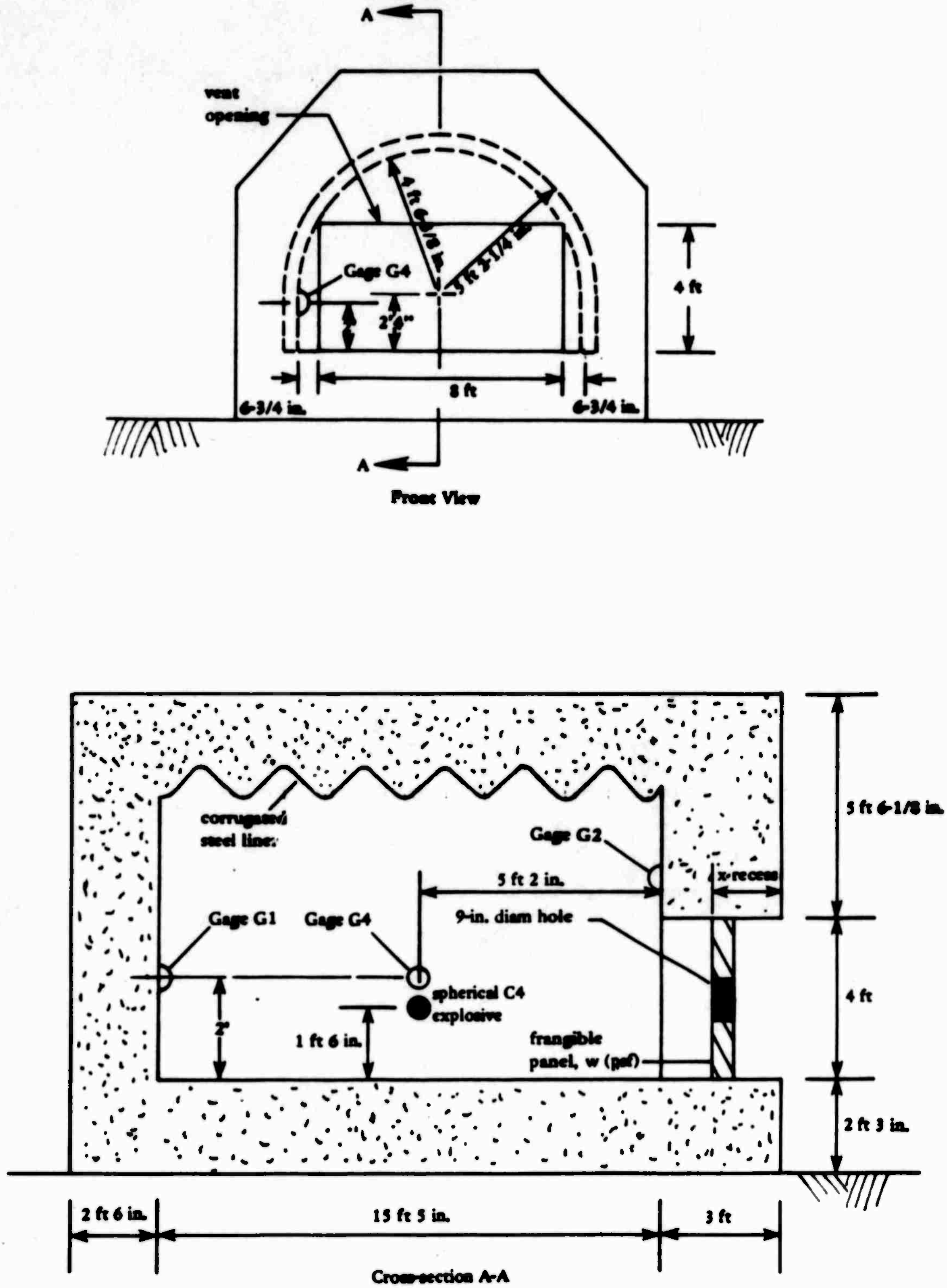


Figure 1. Scale model missile test cell.

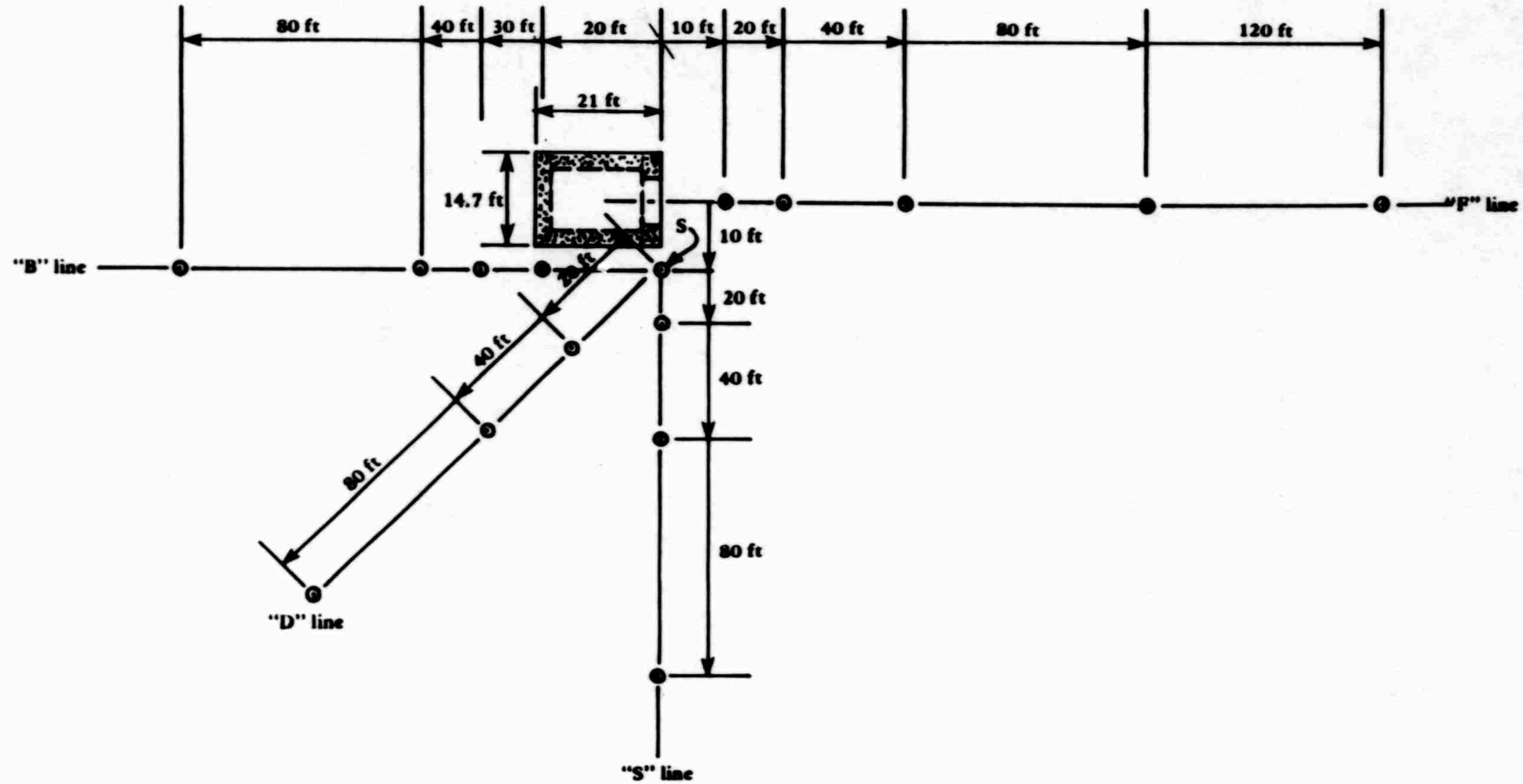
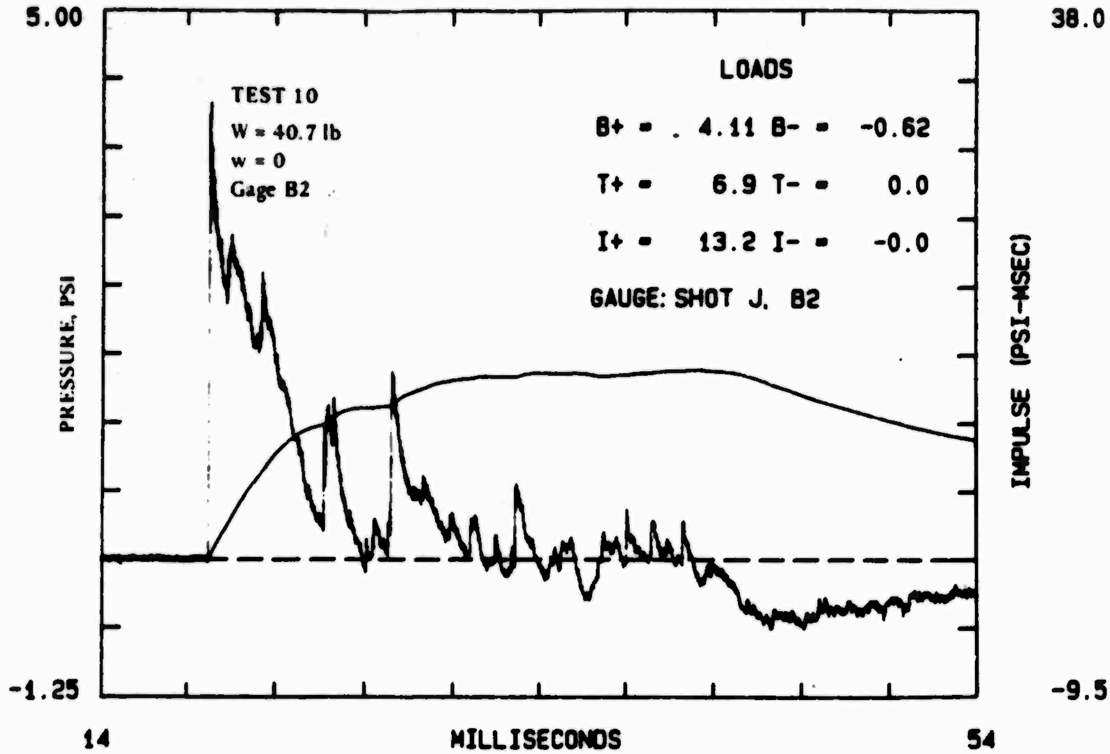


Figure 2. External pressure gage locations.



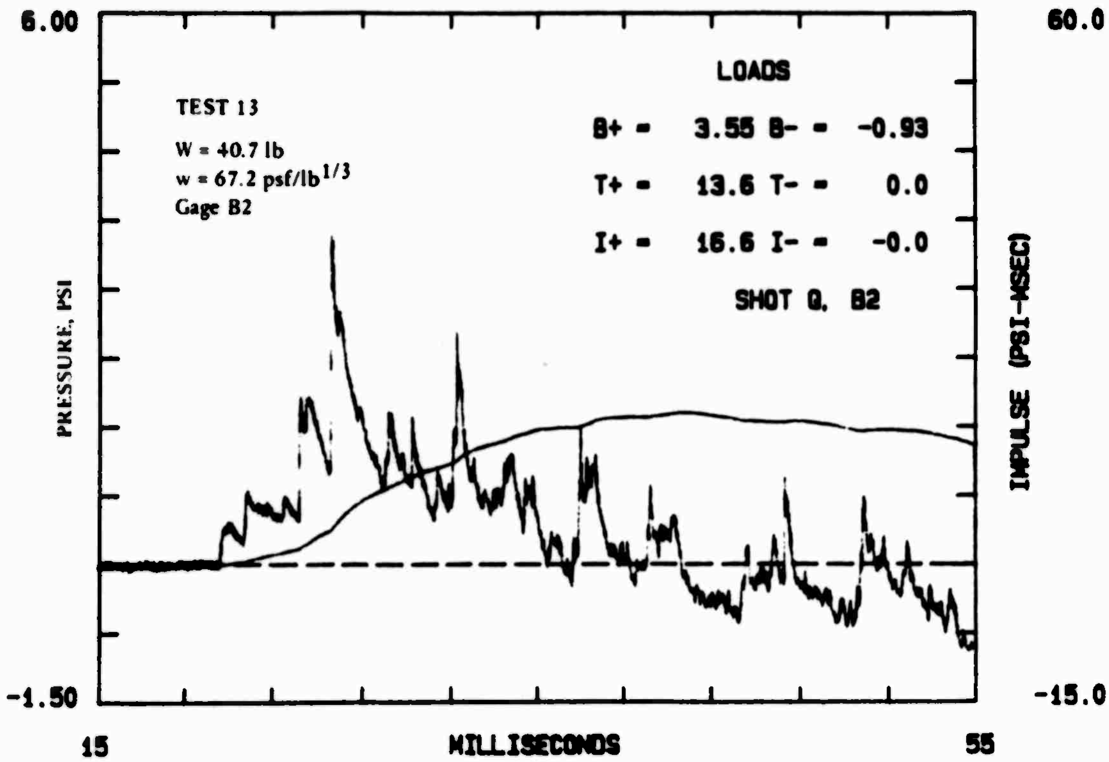
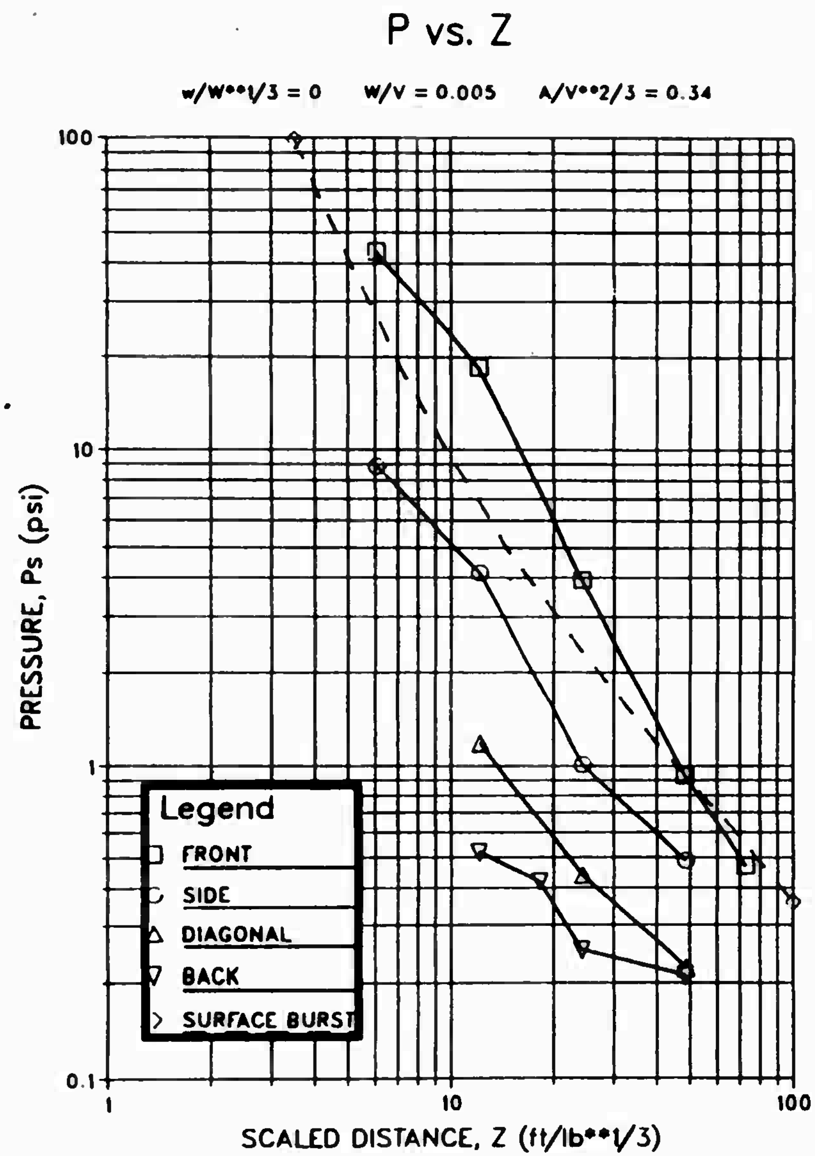


Figure 3. Sample pressure time histories, w = 40.7 lb, with and without vent cover.



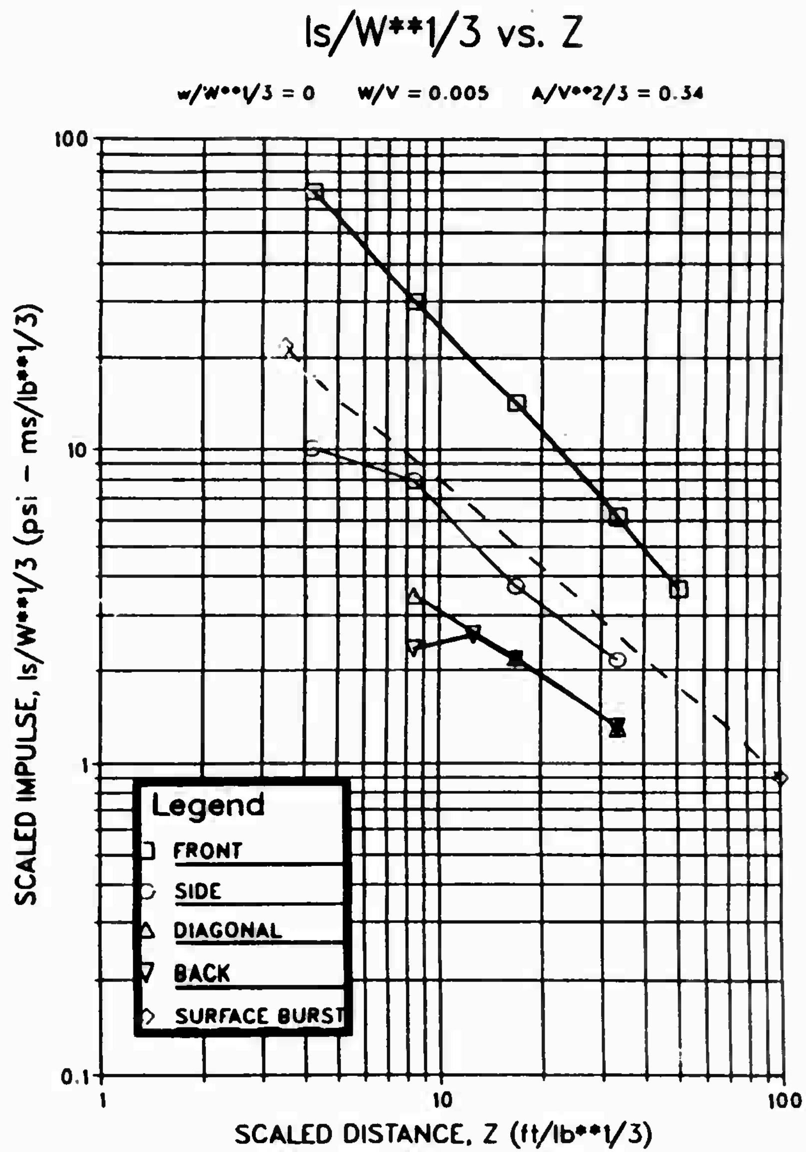


Figure 4. Blast environment vs. direction for $W/V = 0.005\ lb/ft^3$ and $w/W^{1/3} = 0$.

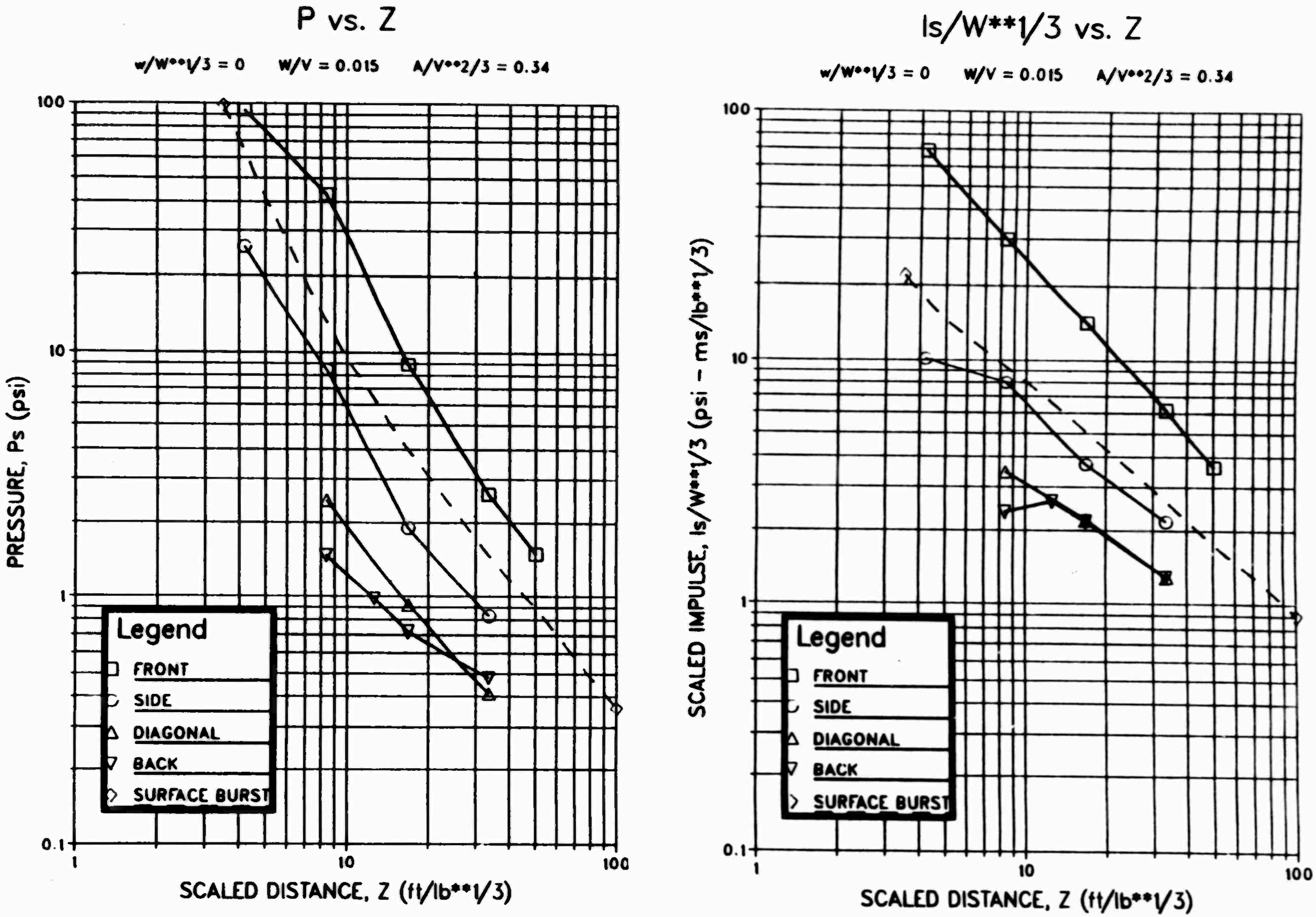


Figure 5. Blast environment vs. direction for $W/V = 0.015$ lb/ft^3 and $w/W^{1/3} = 0$.

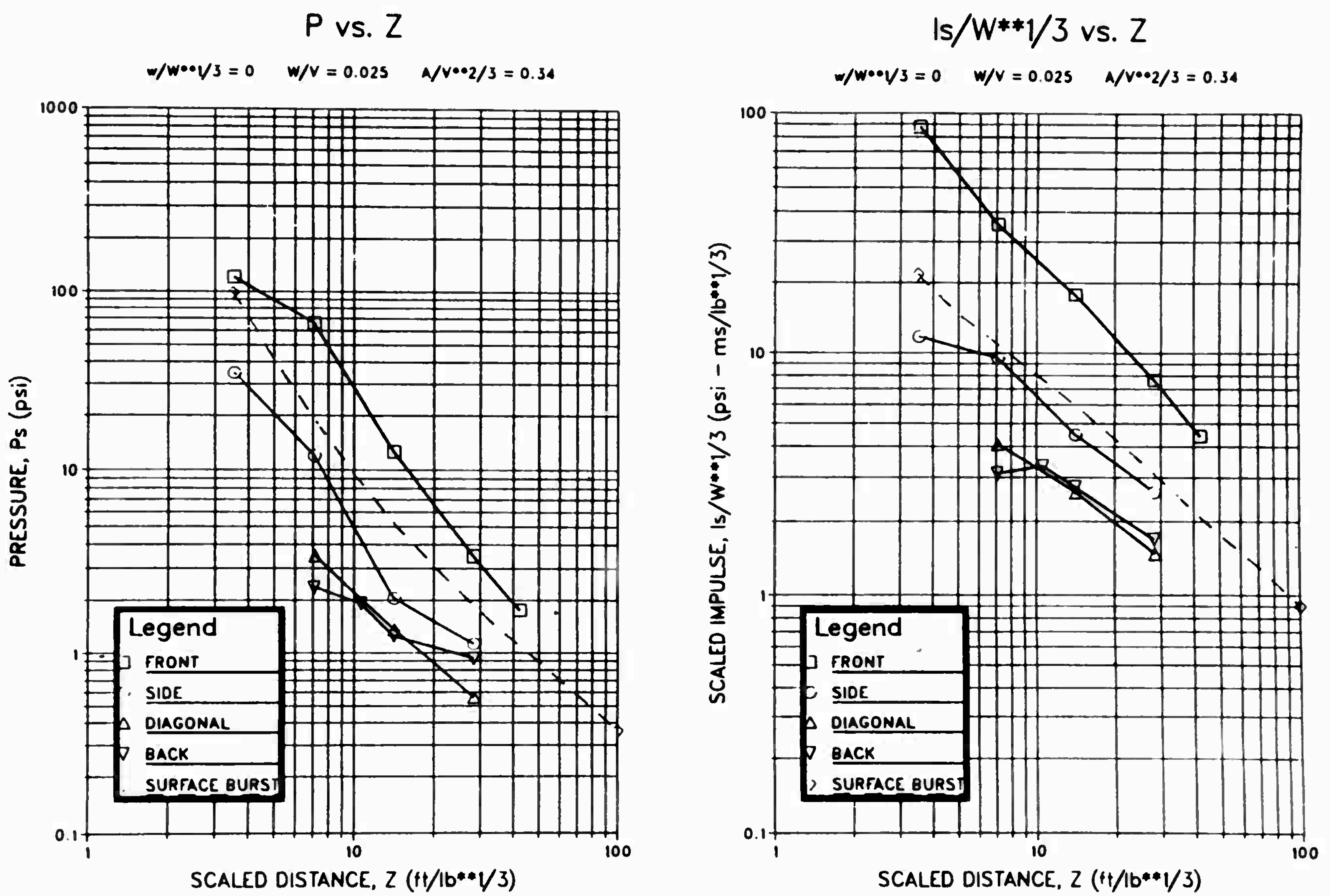


Figure 6. Blast environment vs. direction for $W/V = 0.025\ lb/ft^3$ and $w/W^{1/3} = 0$.

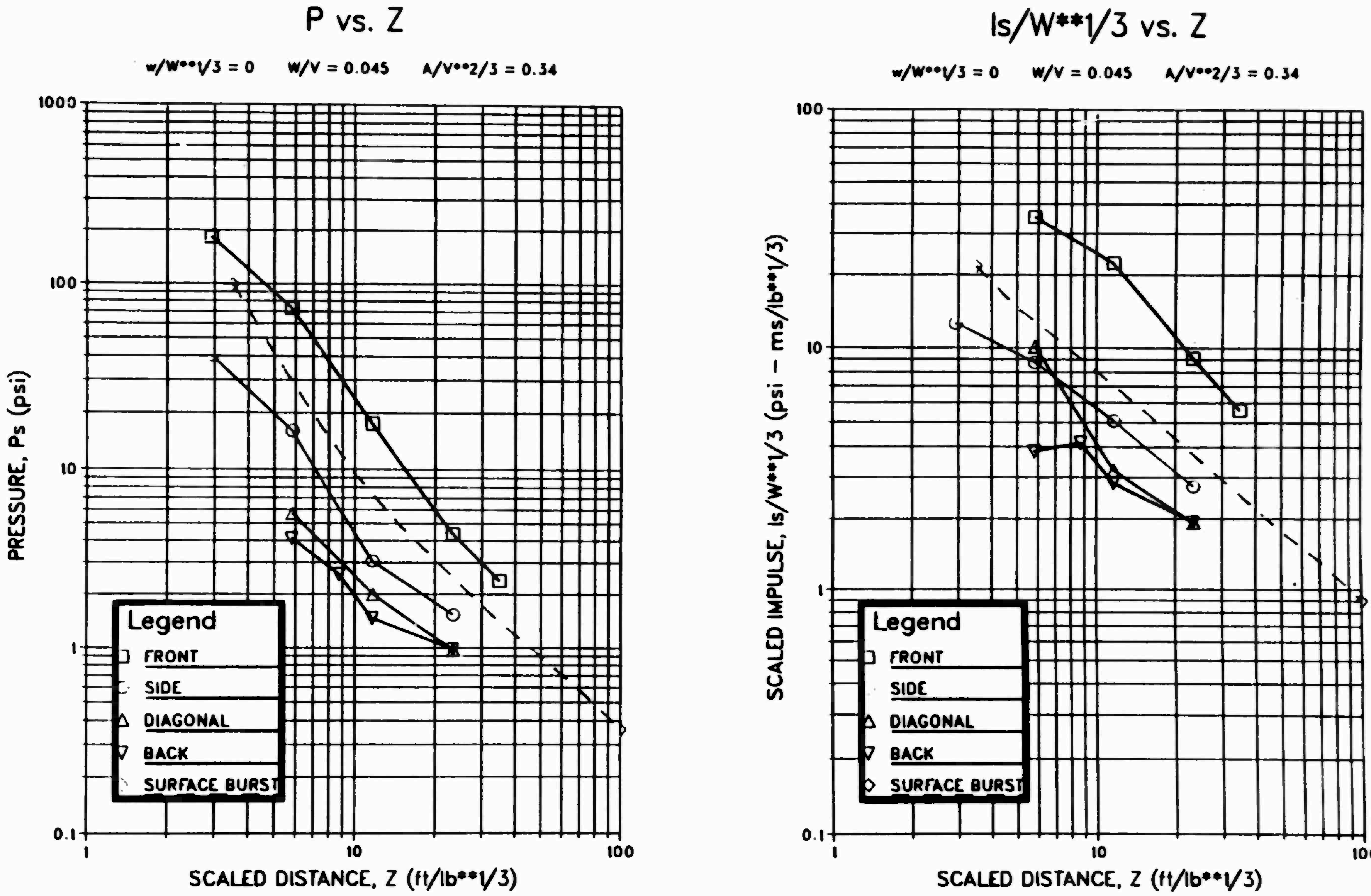


Figure 7. Blast environment vs. direction for $W/V = 0.045\ lb/ft^3$ and $w/W^{1/3} = 0$.

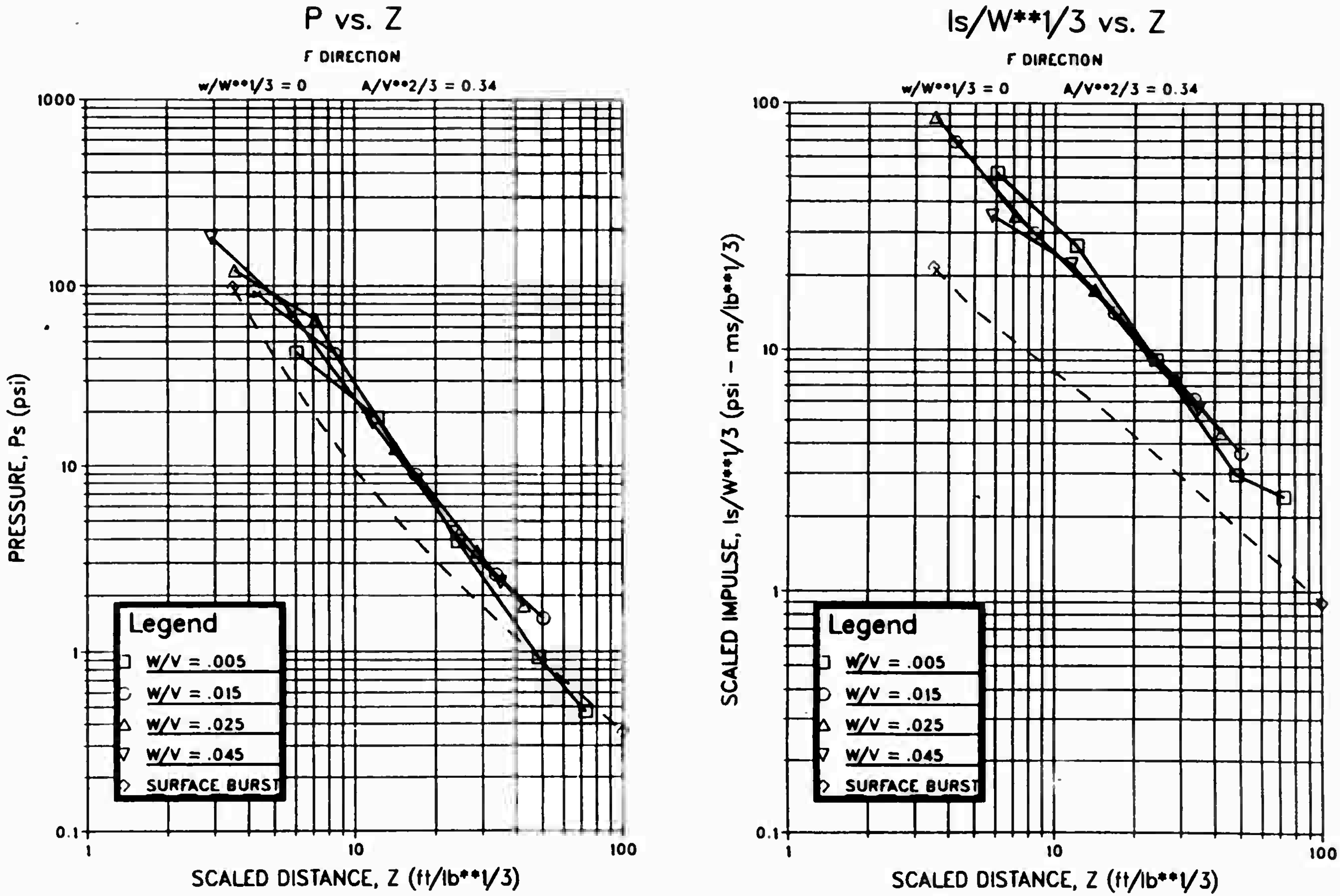


Figure 8. Blast environment vs. W/V for "F" direction and $w/W^{1/3} = 0$.

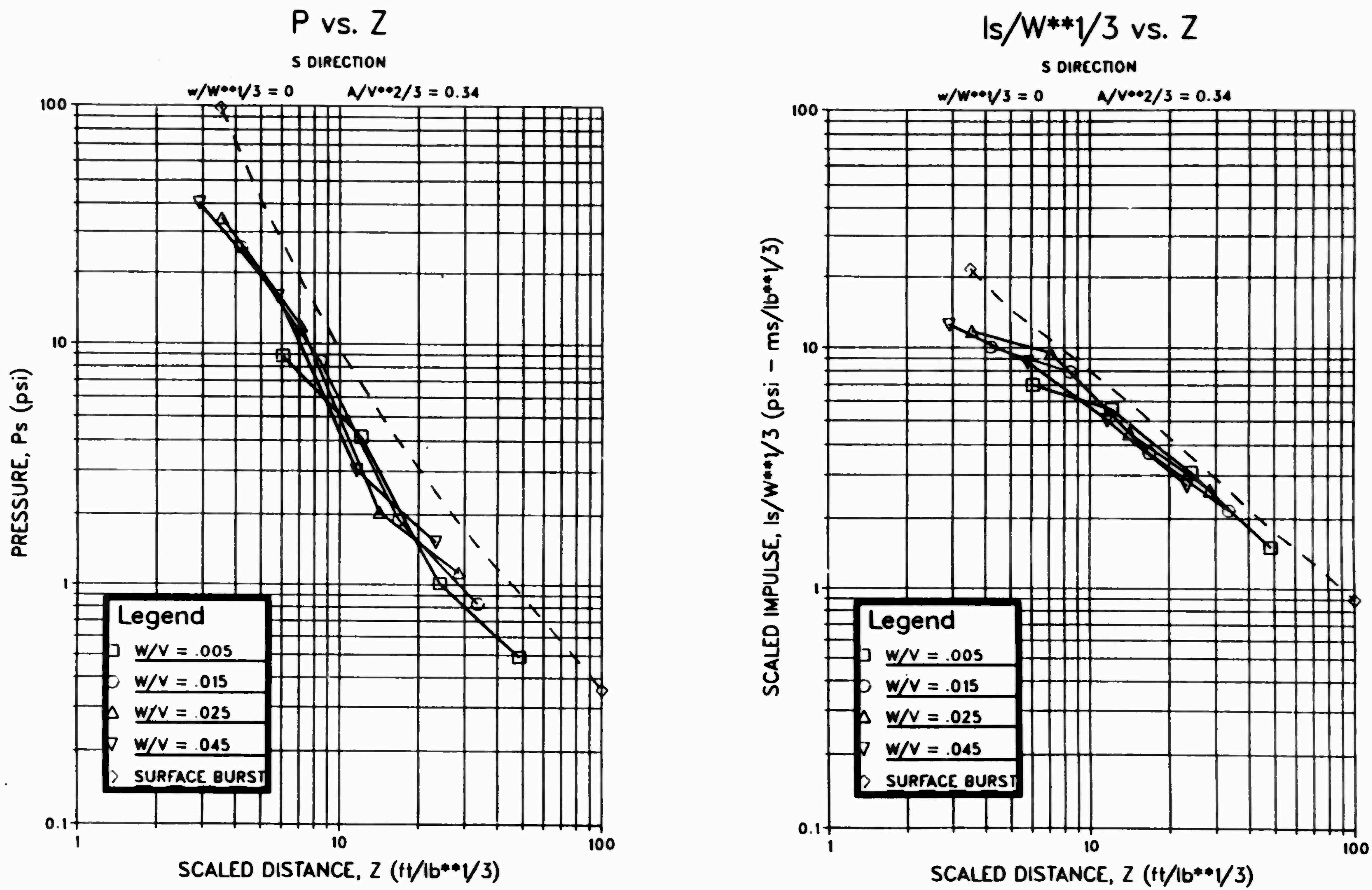


Figure 9. Blast environment vs. W/V for "S" direction and $w/W^{1/3} = 0$.

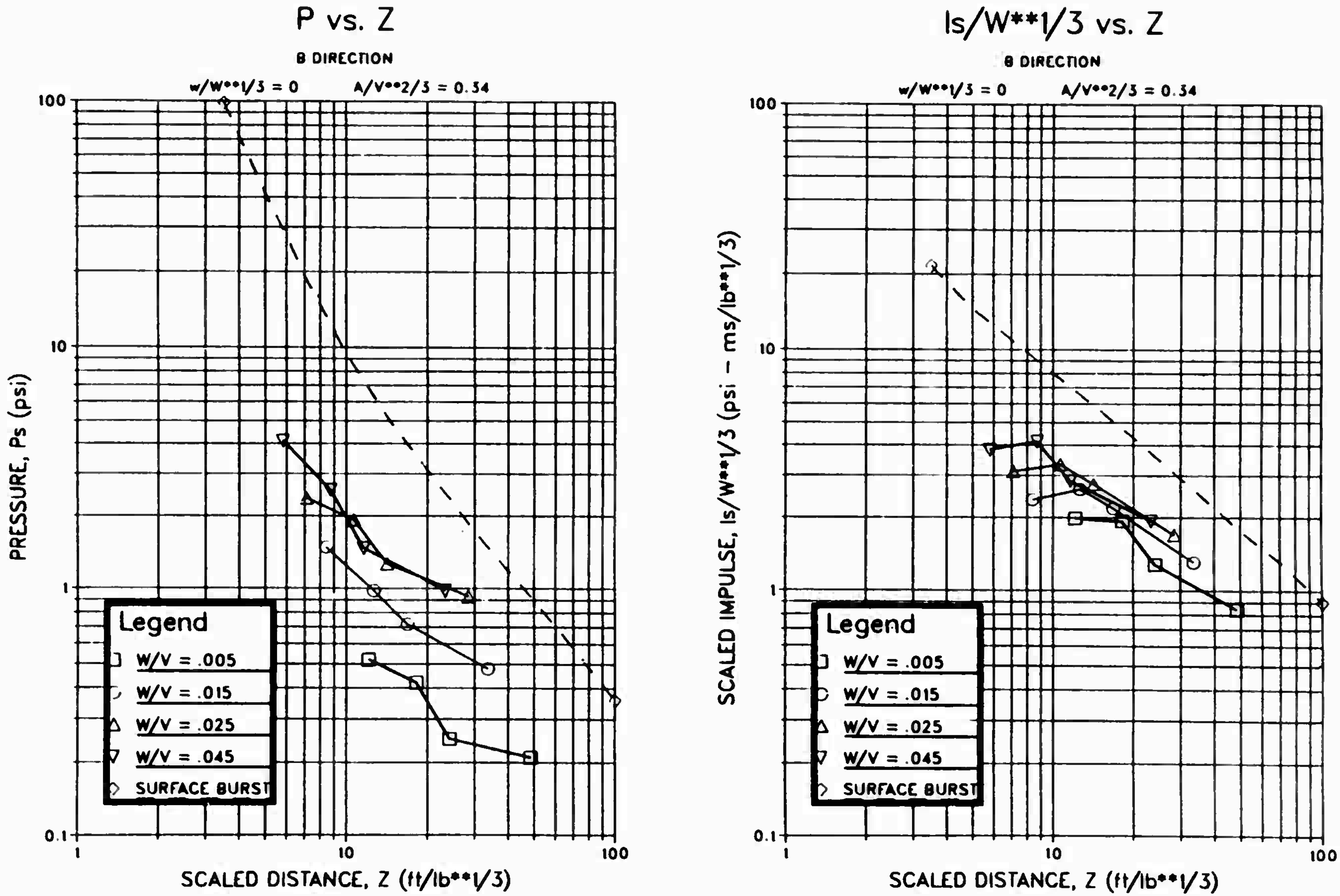
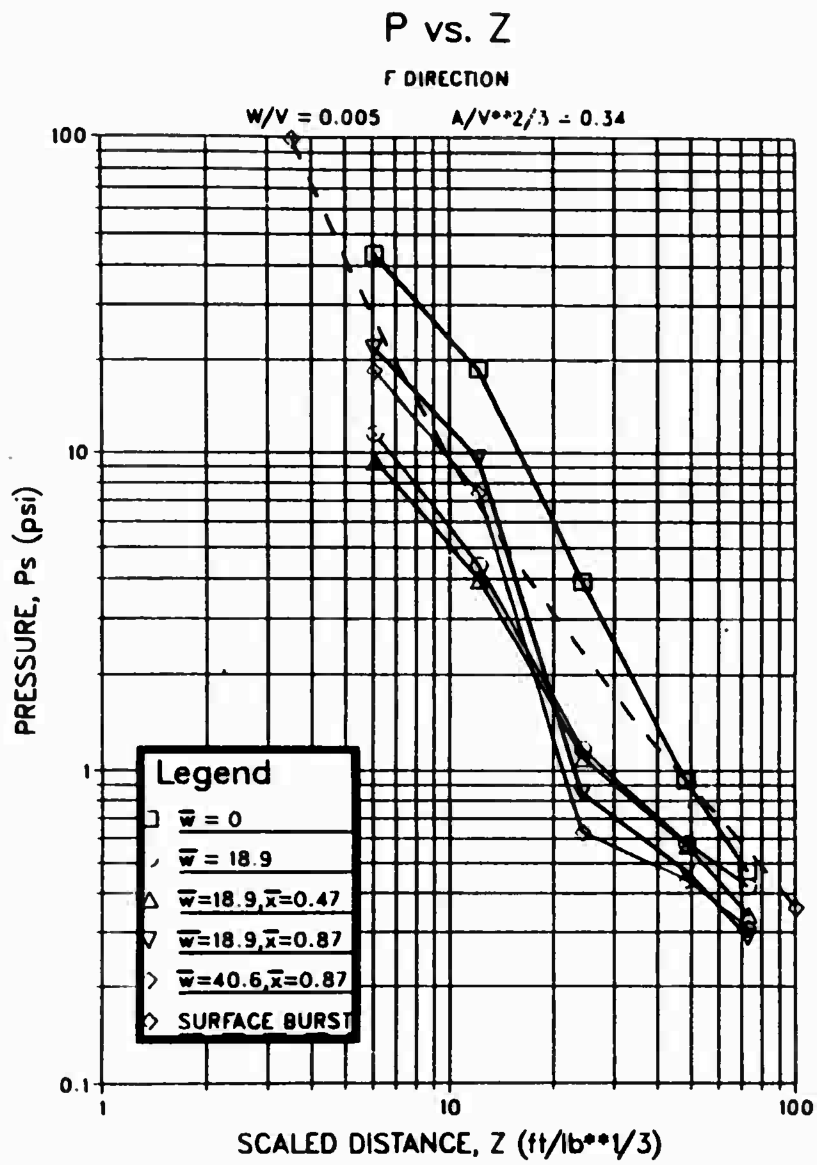


Figure 10. Blast environment vs. W/V for "B" direction and $w/W^{1/3} = 0$.



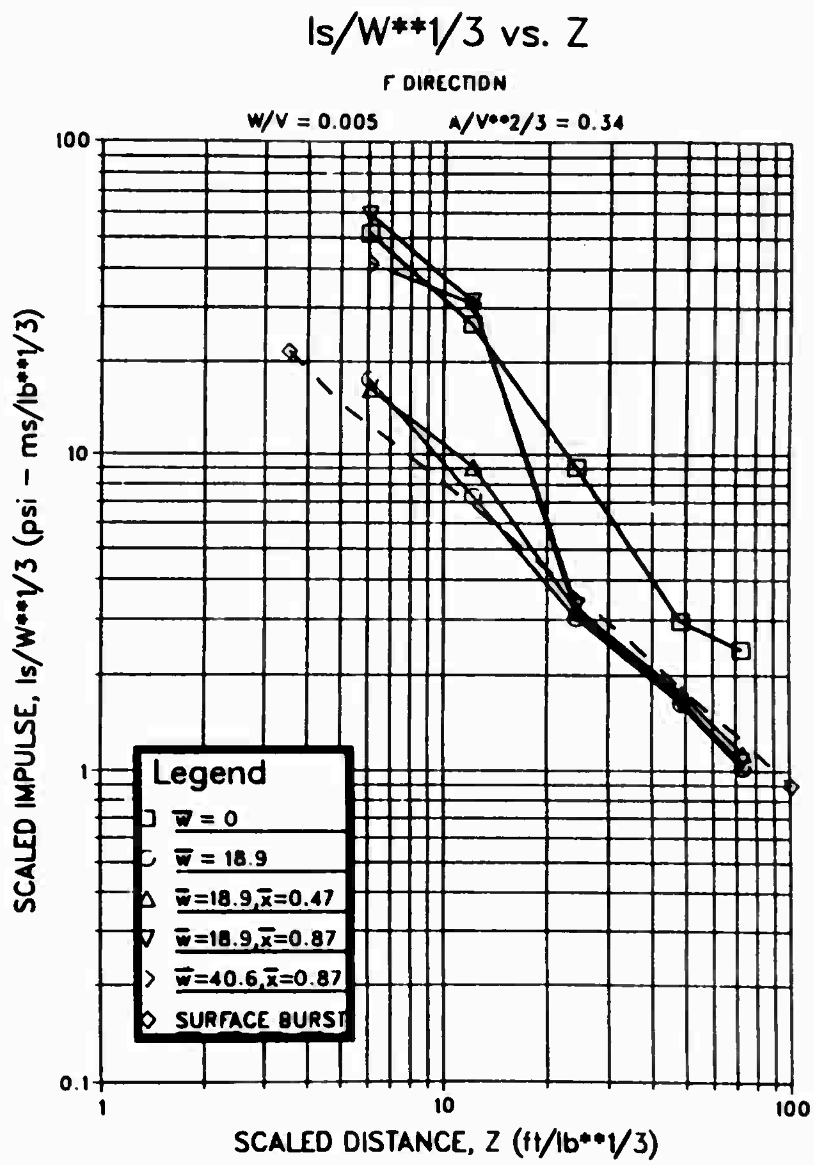


Figure 11. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "F" direction for W/V = 0.005 lb/ft^3.

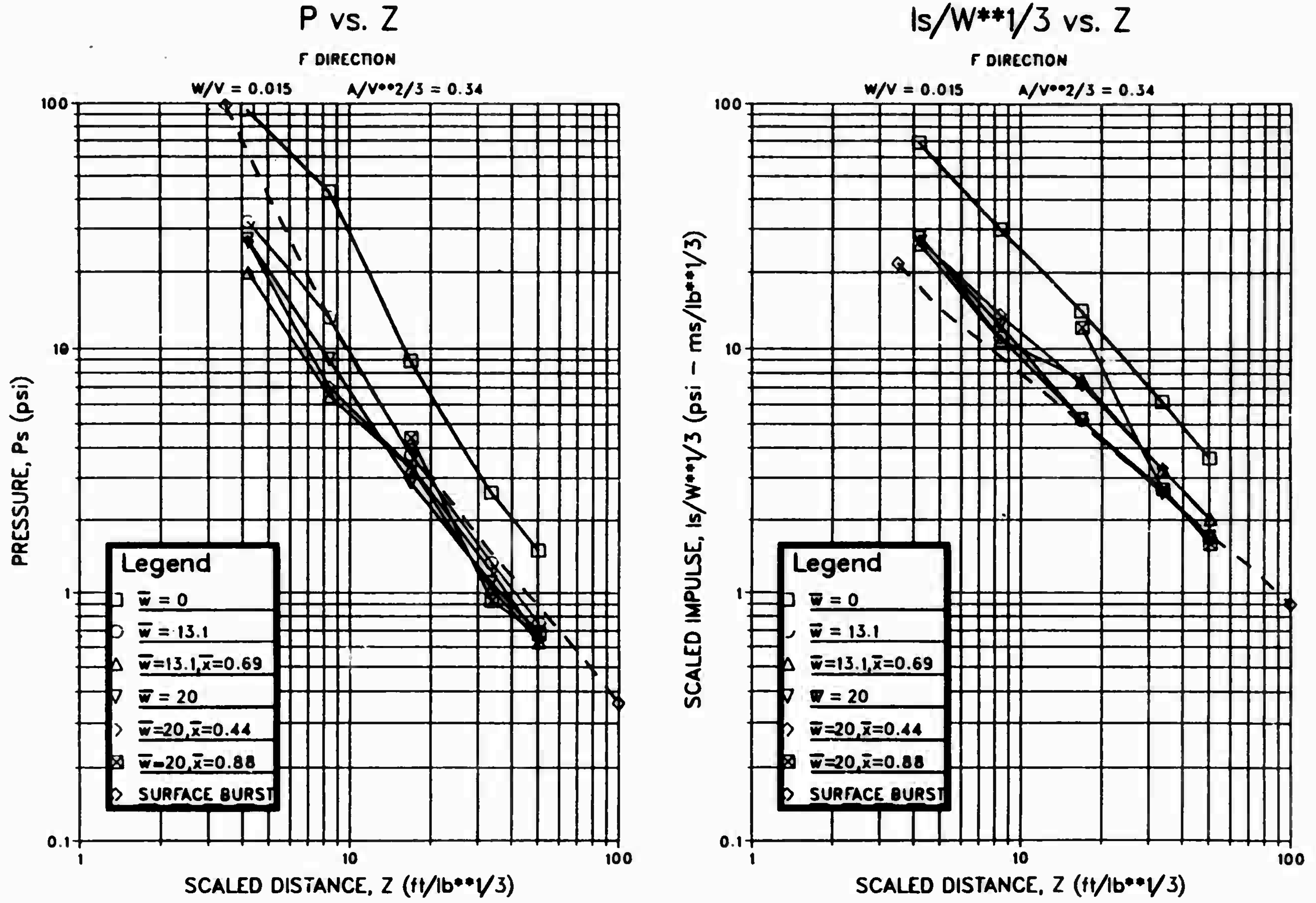


Figure 12. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "F" direction for $W/V = 0.015$ lb/ft^3.

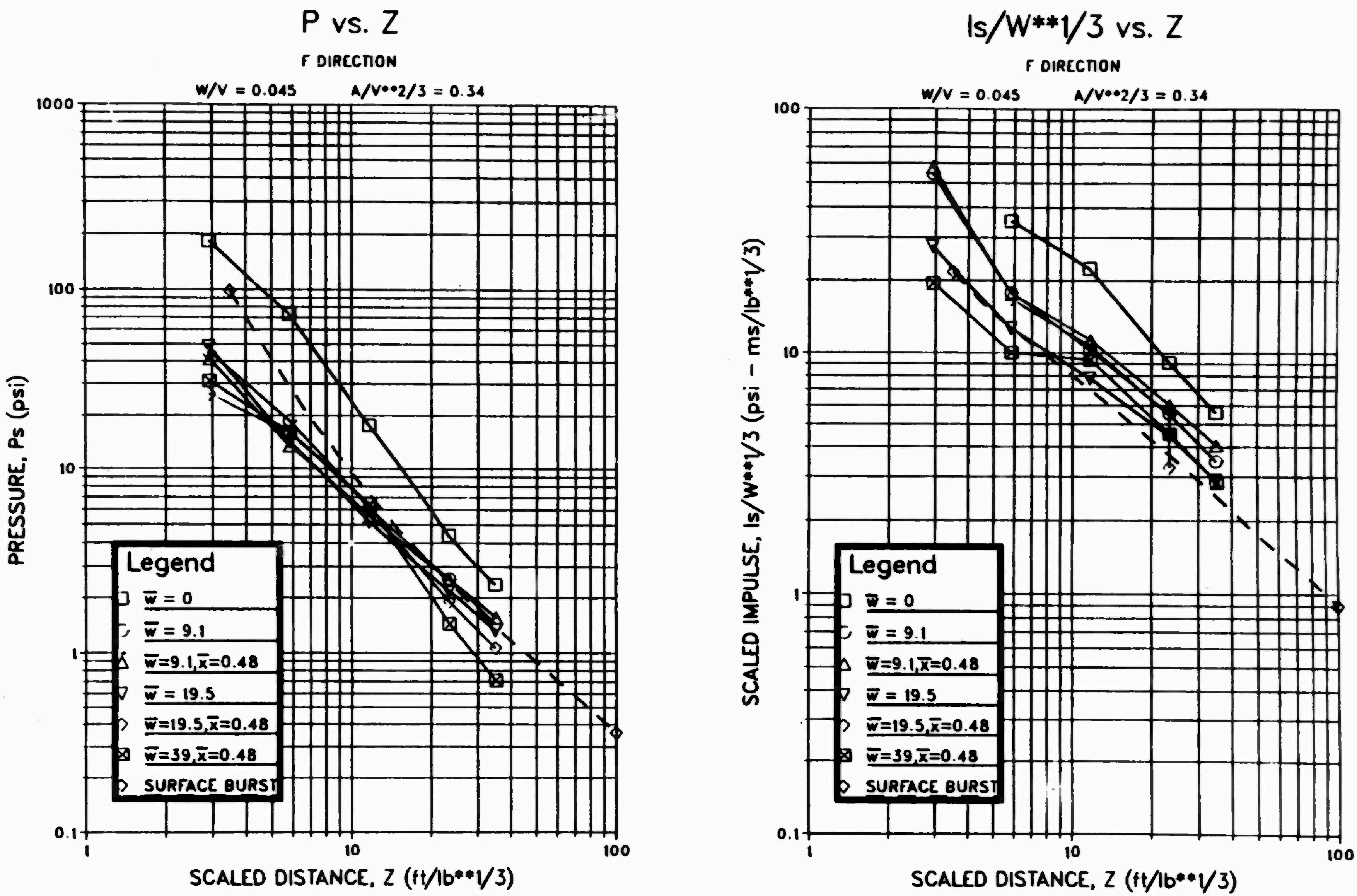


Figure 13. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "F" direction for $W/V = 0.045\ lb/ft^3$.

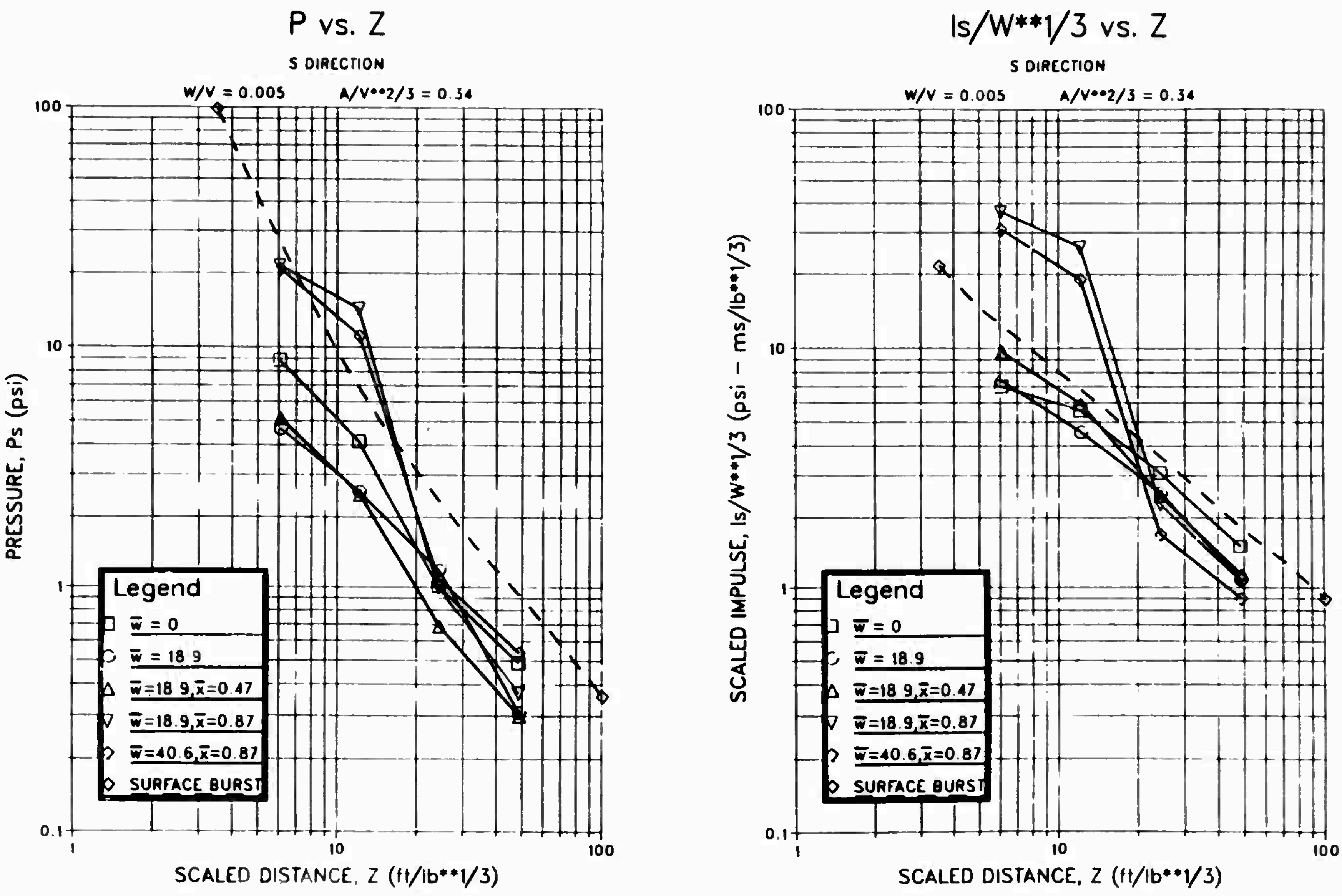


Figure 14. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "S" direction for $W/V = 0.005$ lb/ft^3.

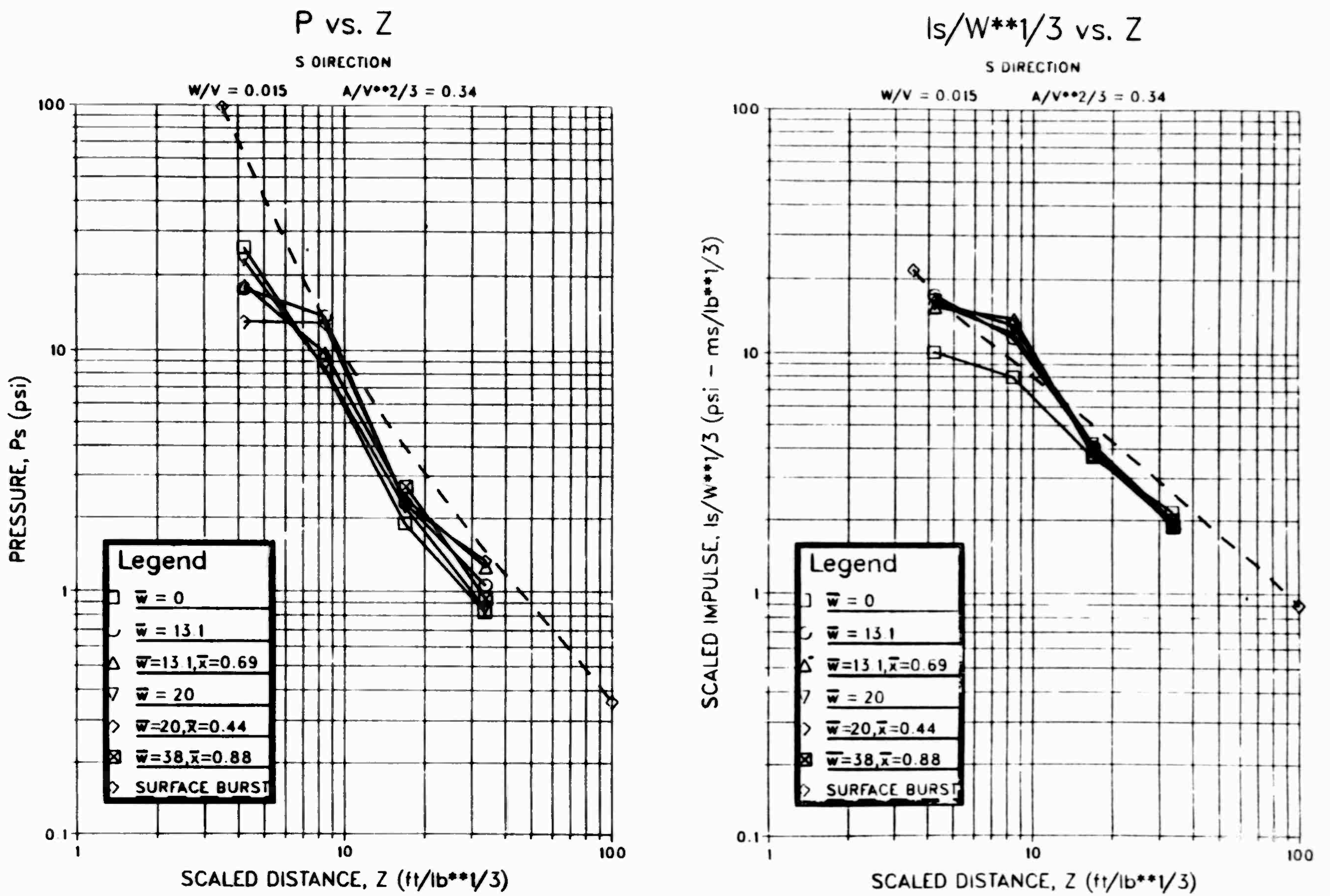


Figure 15. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "S" direction for $W/V = 0.015$ lb/ft^3.

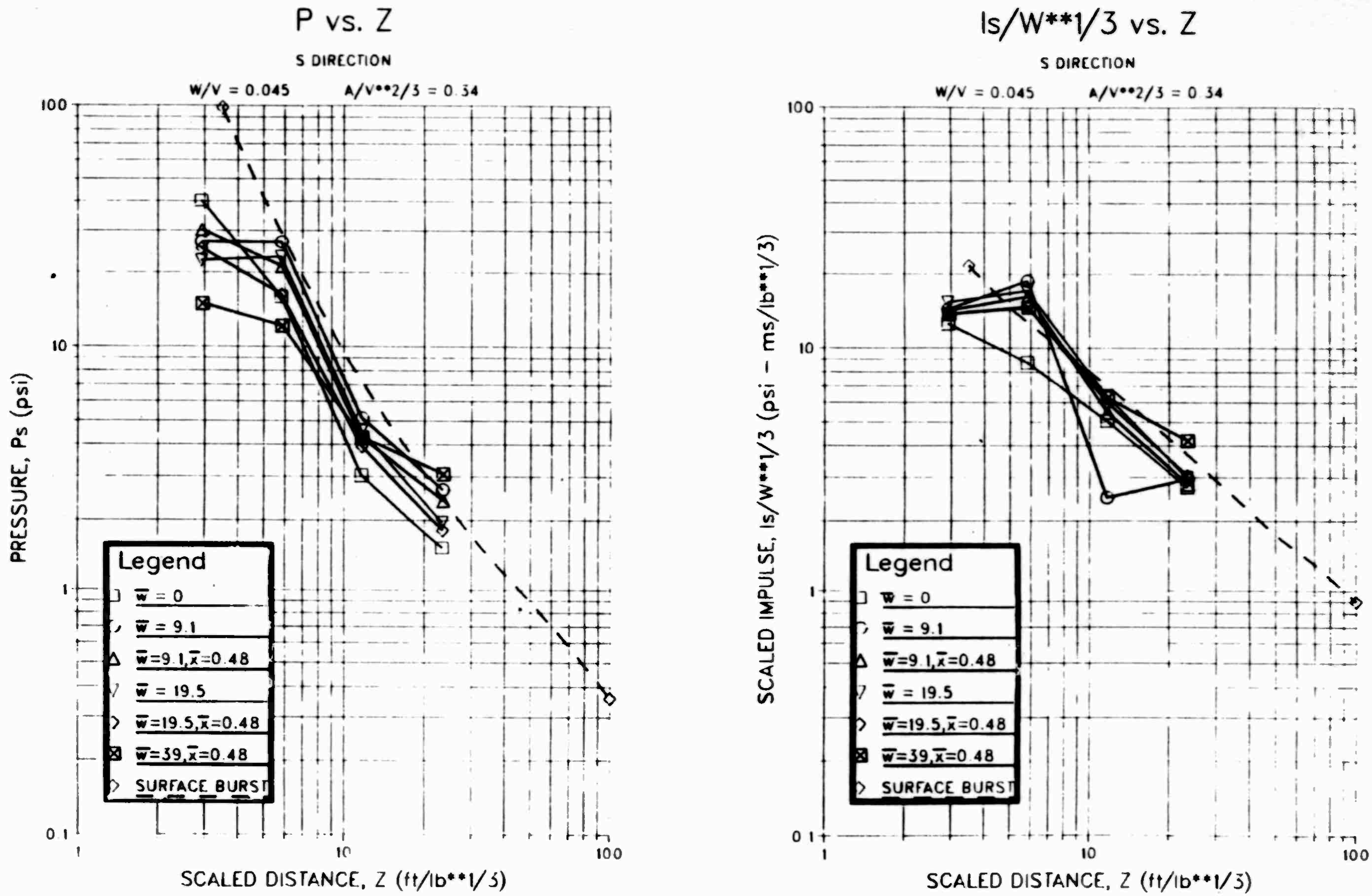
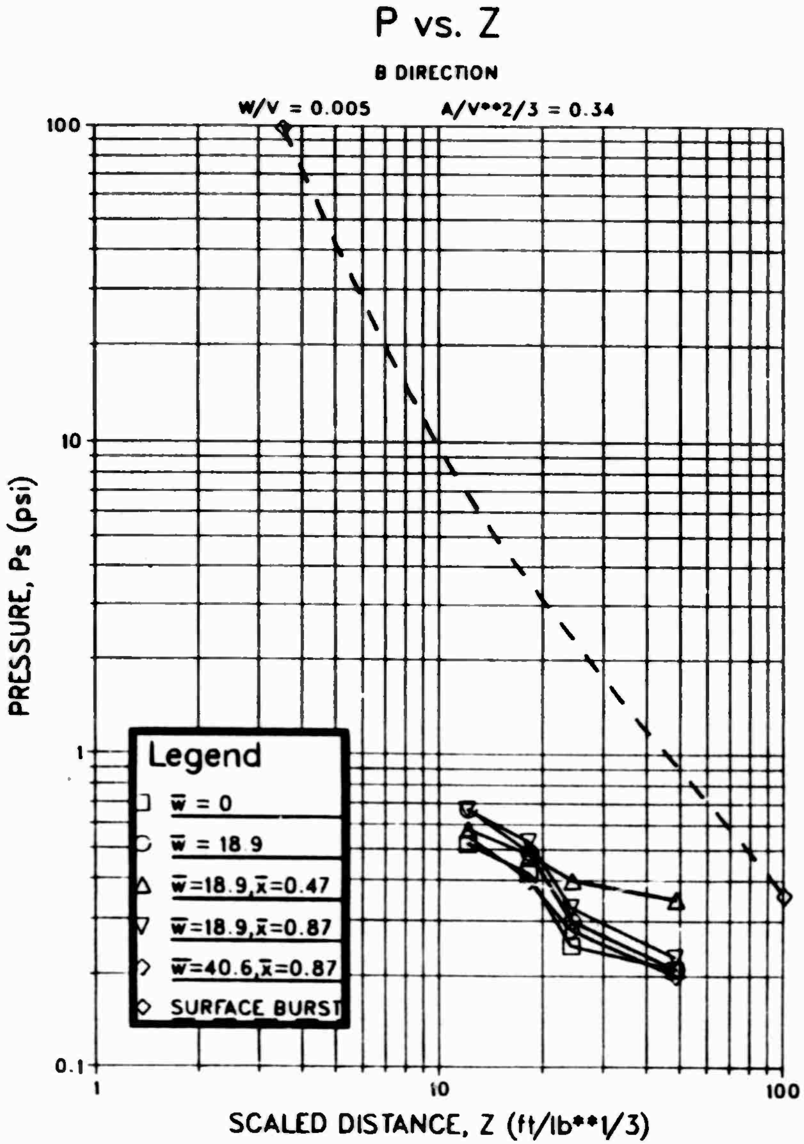


Figure 16. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "S" direction for W/V = 0.045 lb/ft^3.



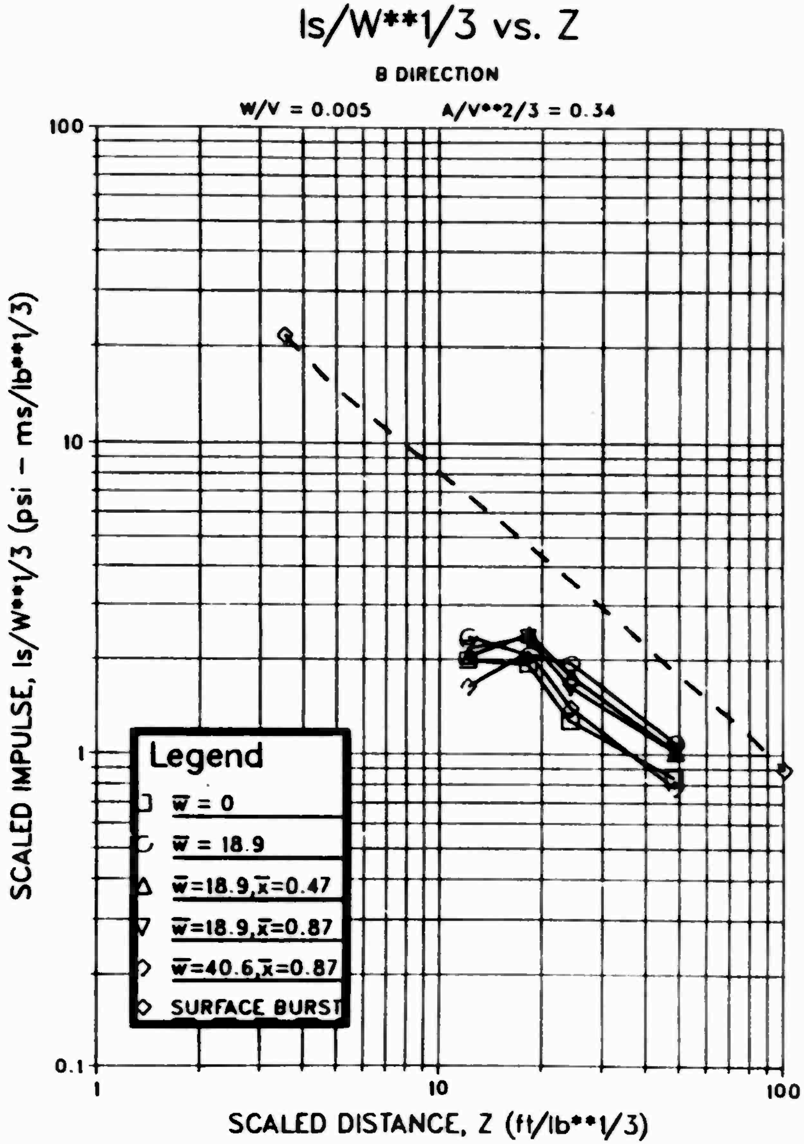


Figure 17. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "B" direction for $W/V = 0.005\ lb/ft^3$.

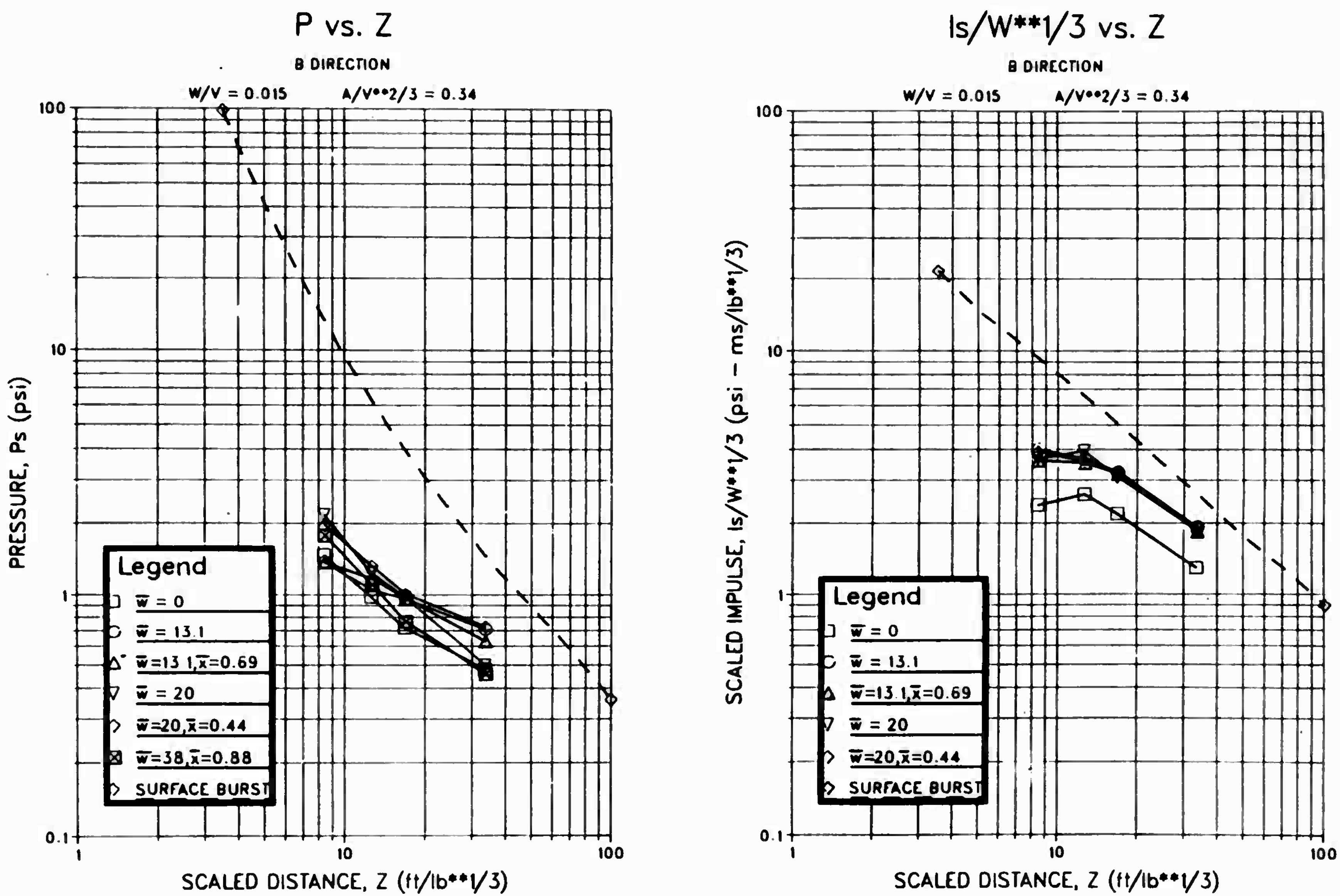


Figure 18. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "B" direction for $W/V = 0.015$ lb/ft^3.

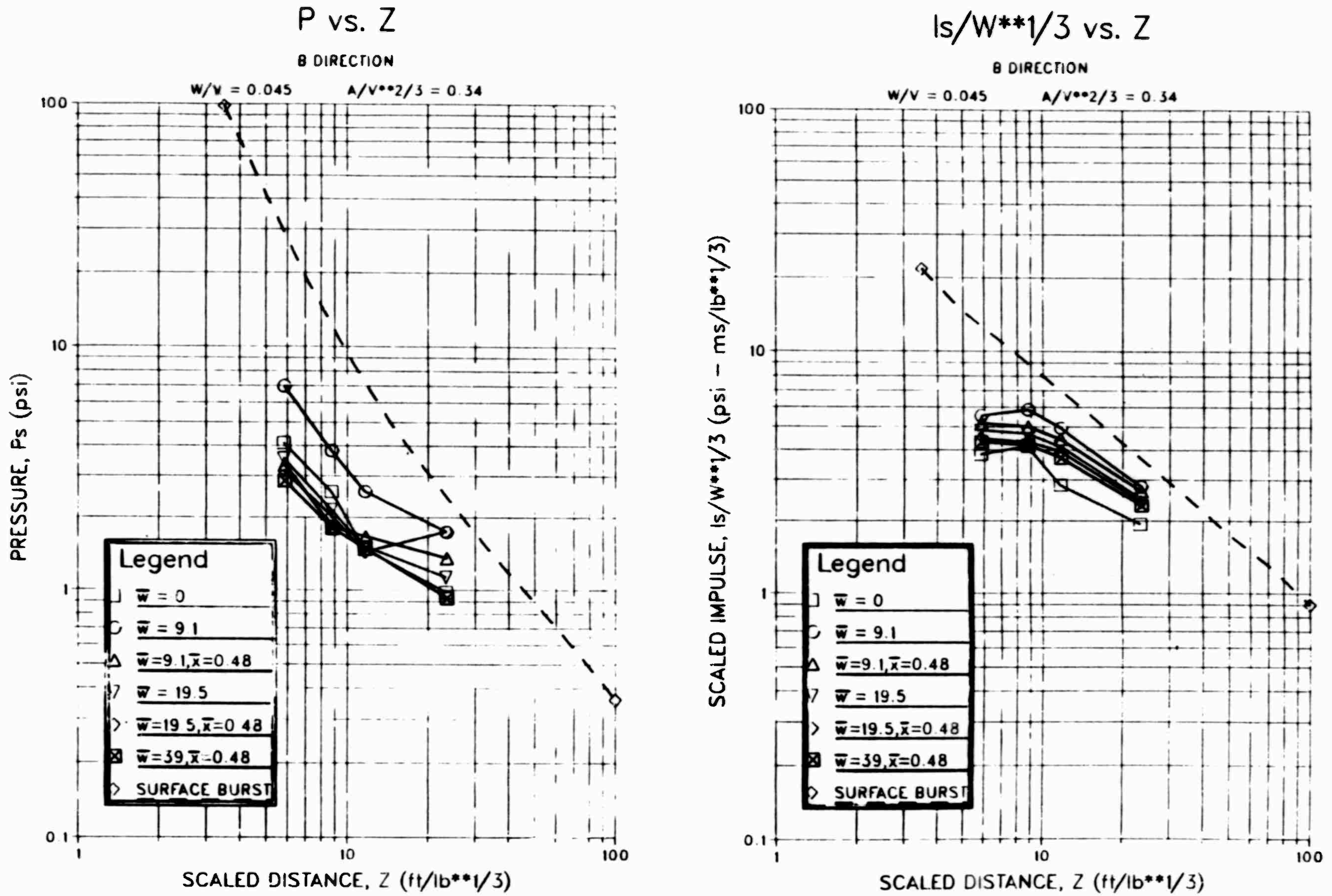


Figure 19. Blast environment vs. $w/W^{1/3}$ and $x/W^{1/3}$ in "B" direction for $W/V = 0.045\ lb/ft^3$.

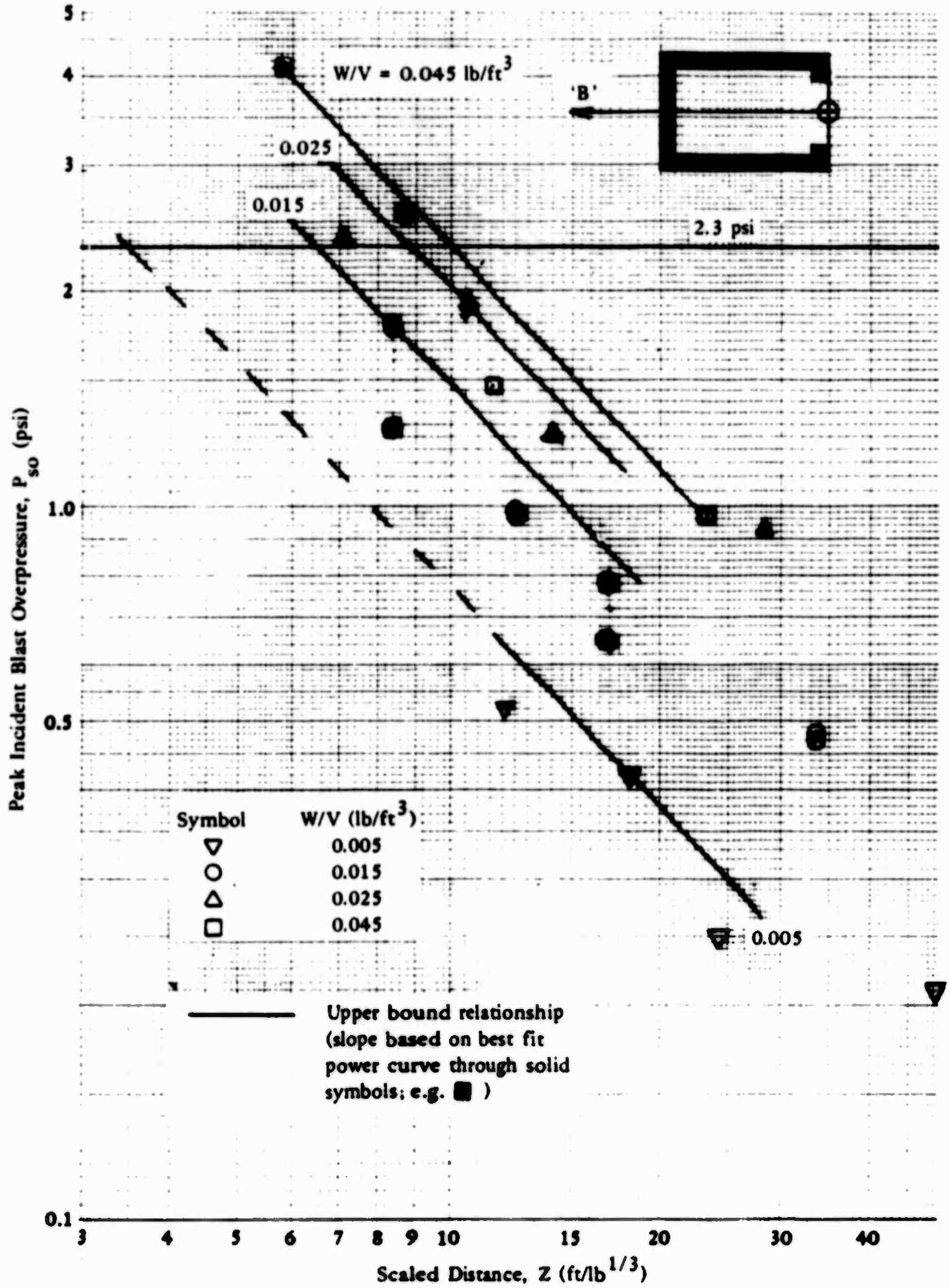


Figure 20. P_{so} vs. W/V to the back ('B' direction) of the MTC.

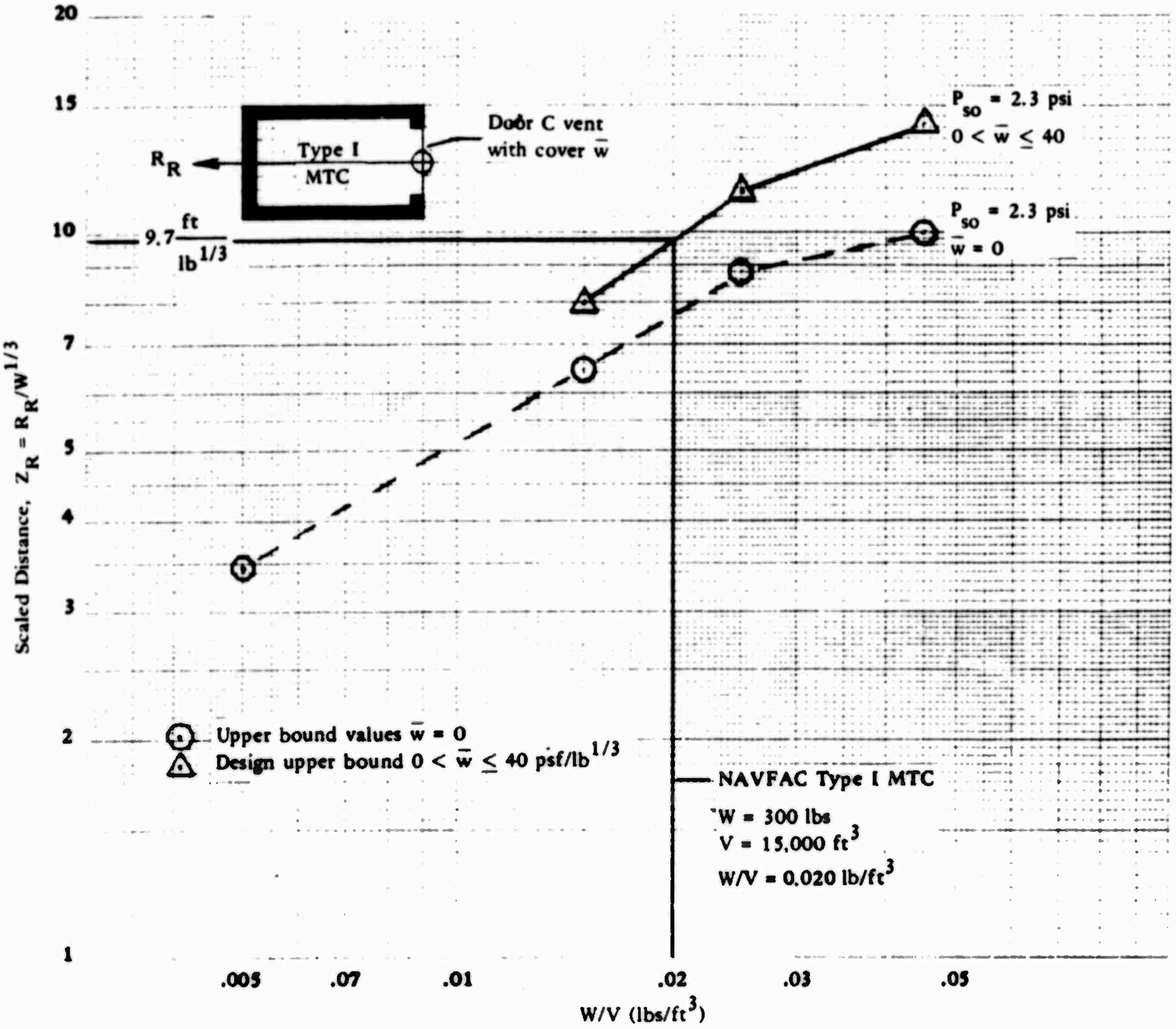


Figure 21. Z_R vs. W/V for P_{so} = 2.3 psi to back of MTC.

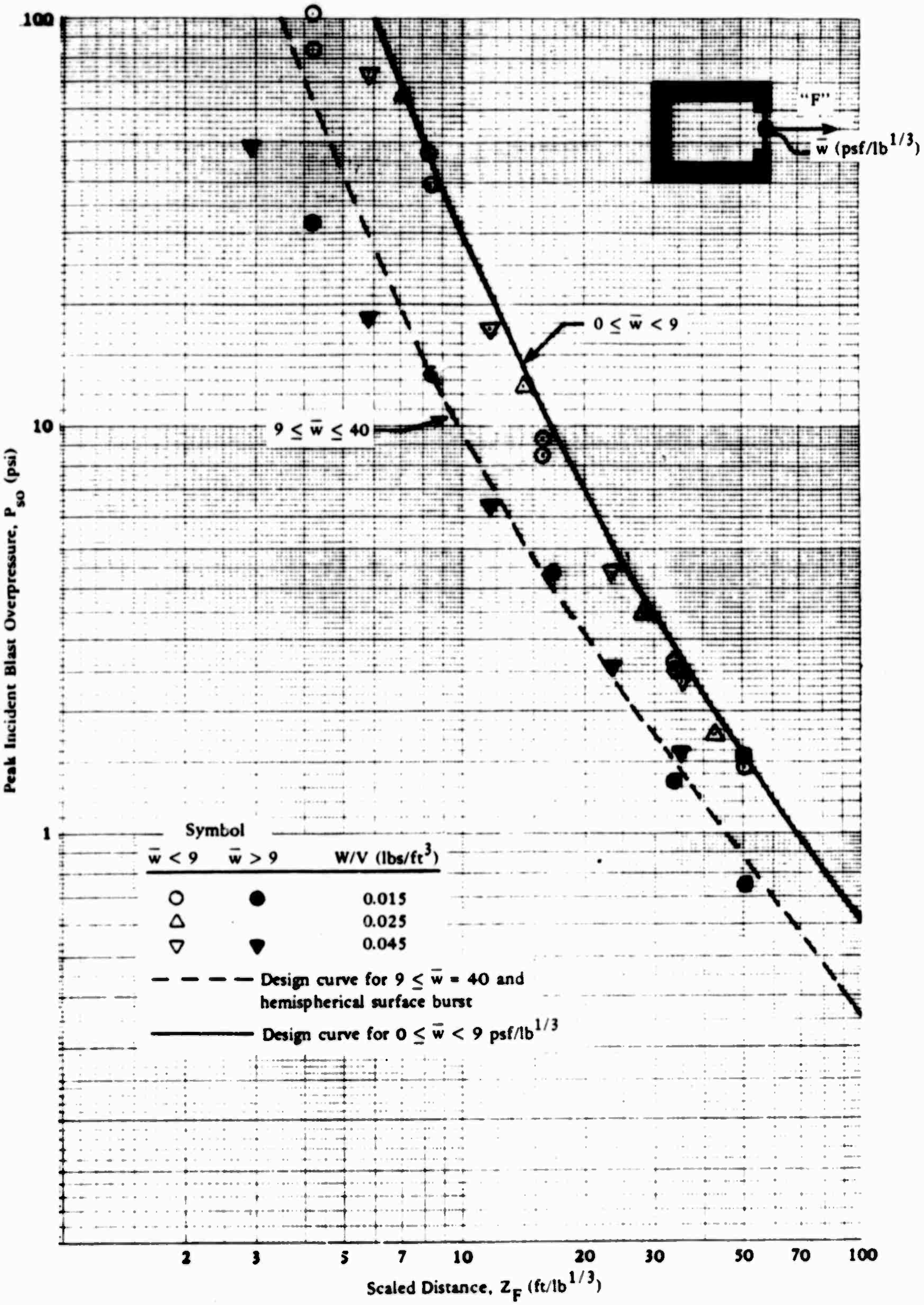


Figure 22. P_{so} design curves, 'F' direction.

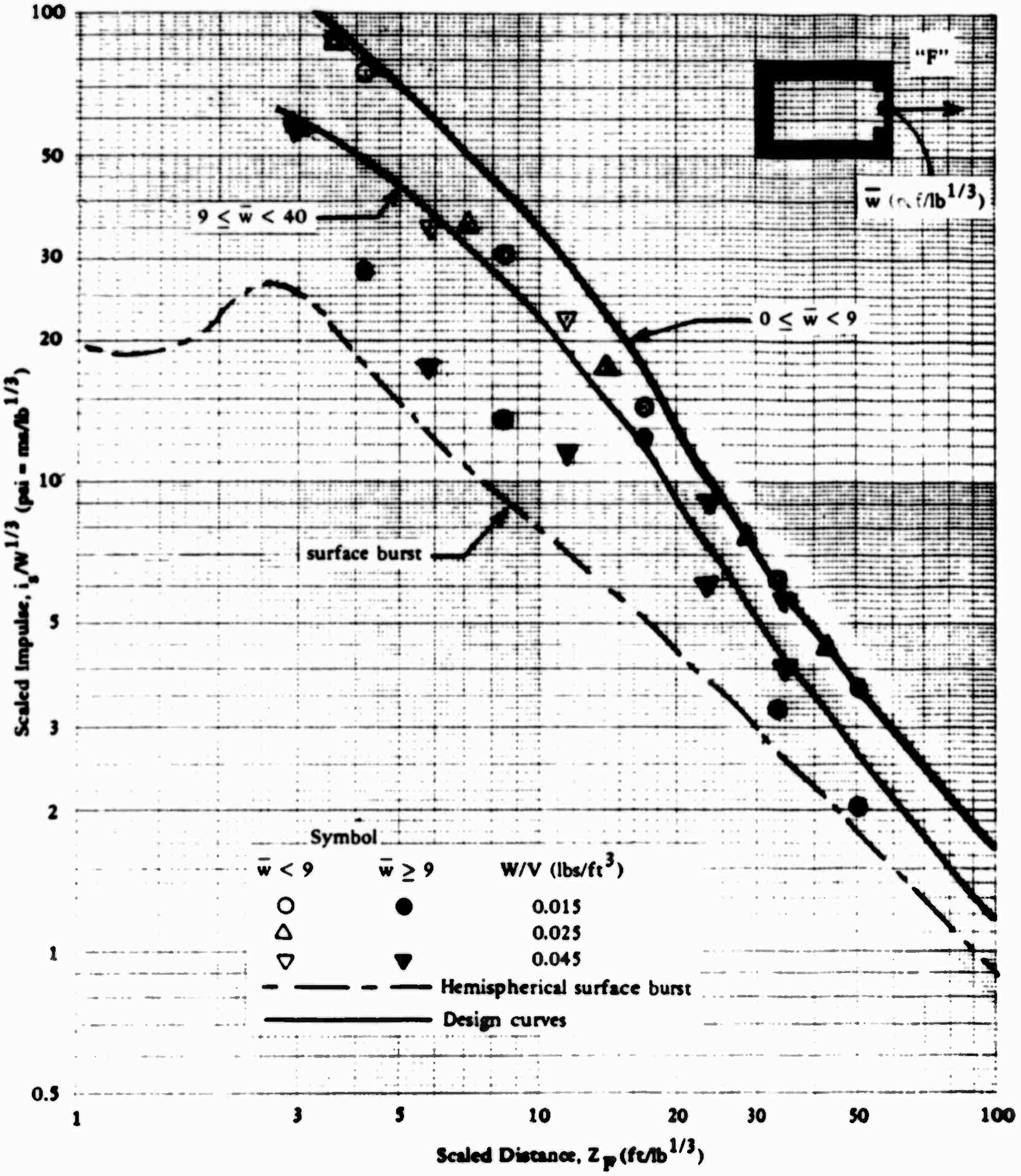


Figure 23. $i_s/W^{1/3}$ design curves, 'F' direction.

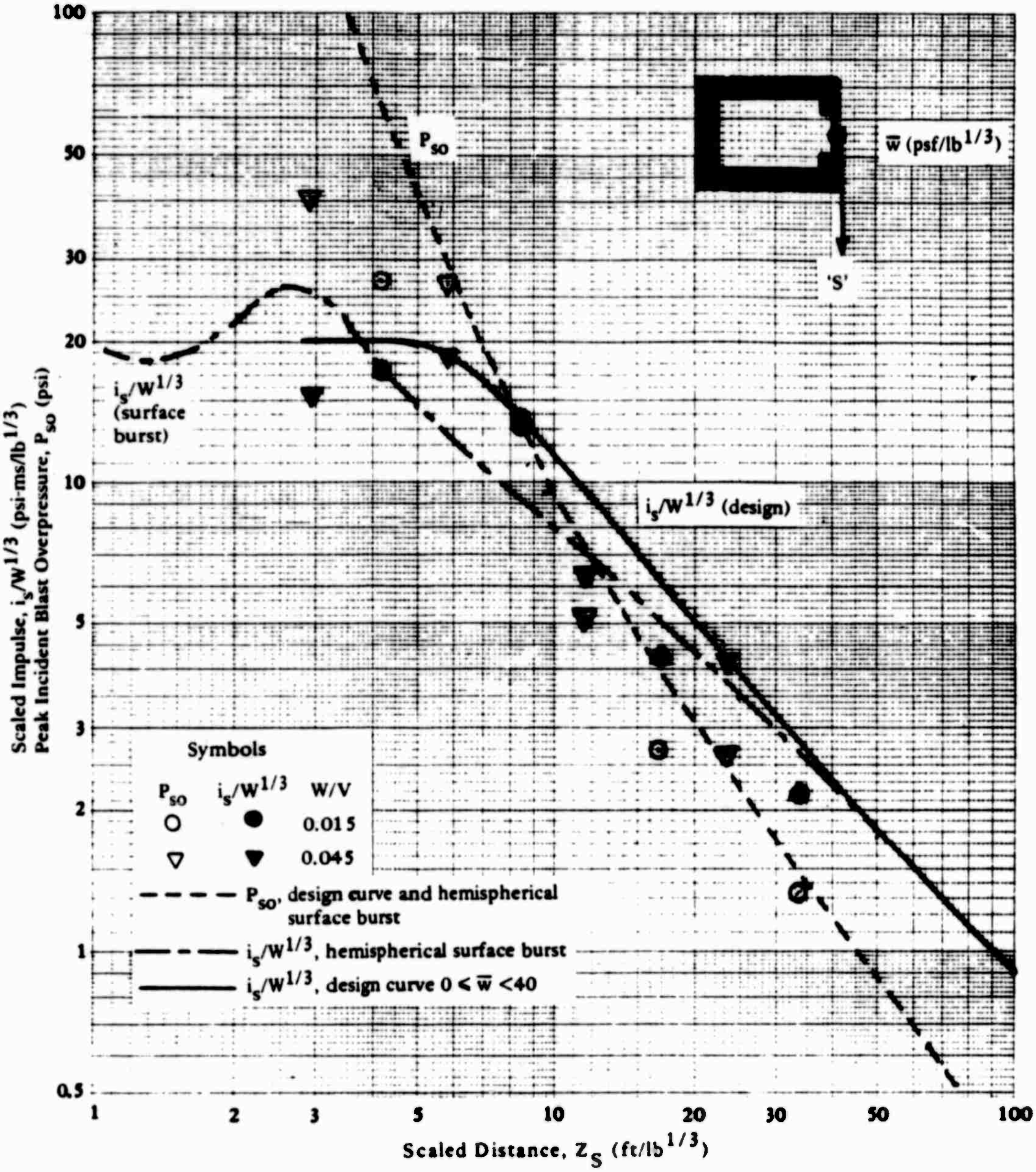


Figure 24. P_{so} and $i_s/W^{1/3}$ design curves, 'S' direction.

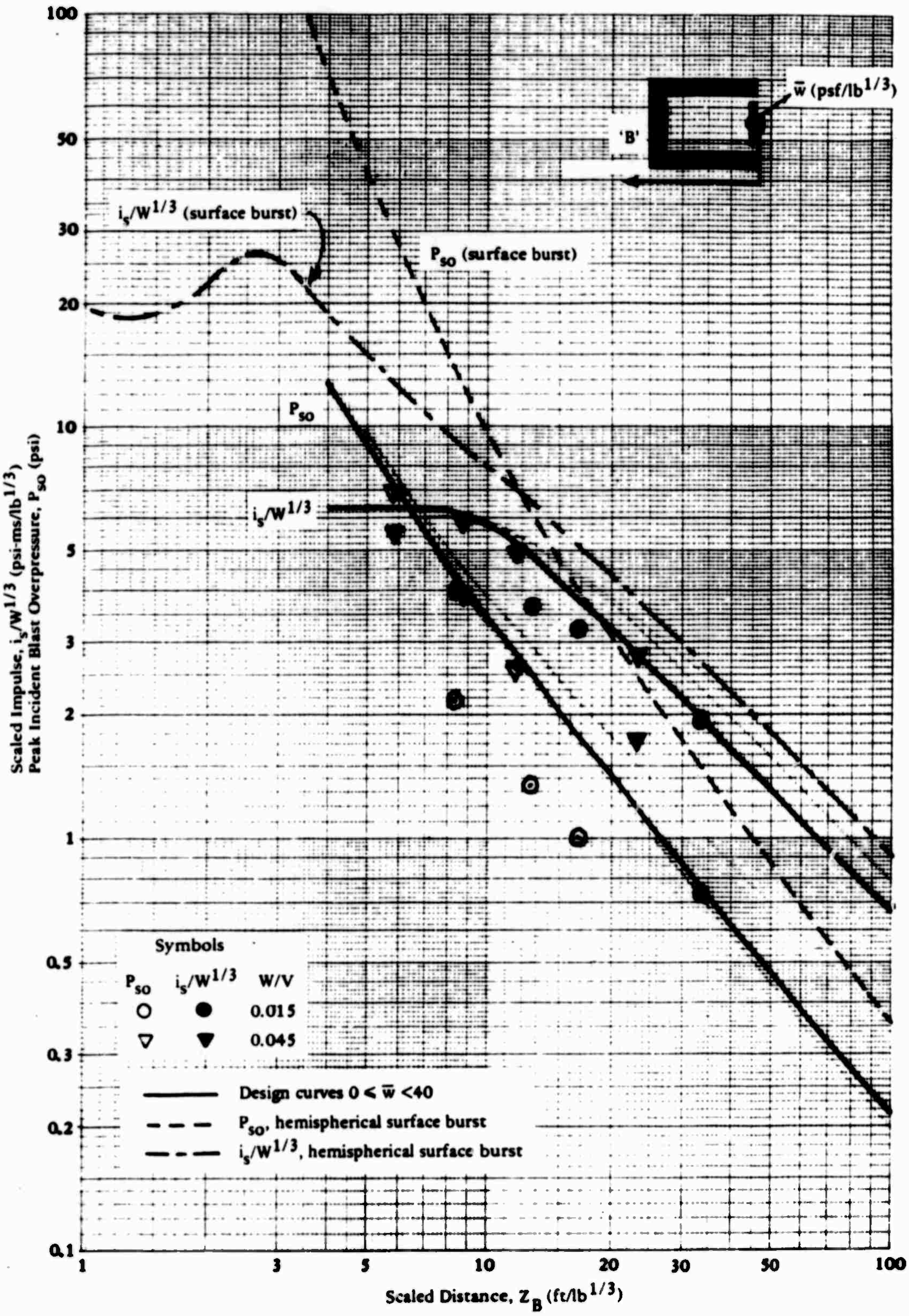


Figure 25. P_{so} and $i_s/W^{1/3}$ design curves, 'B' direction.

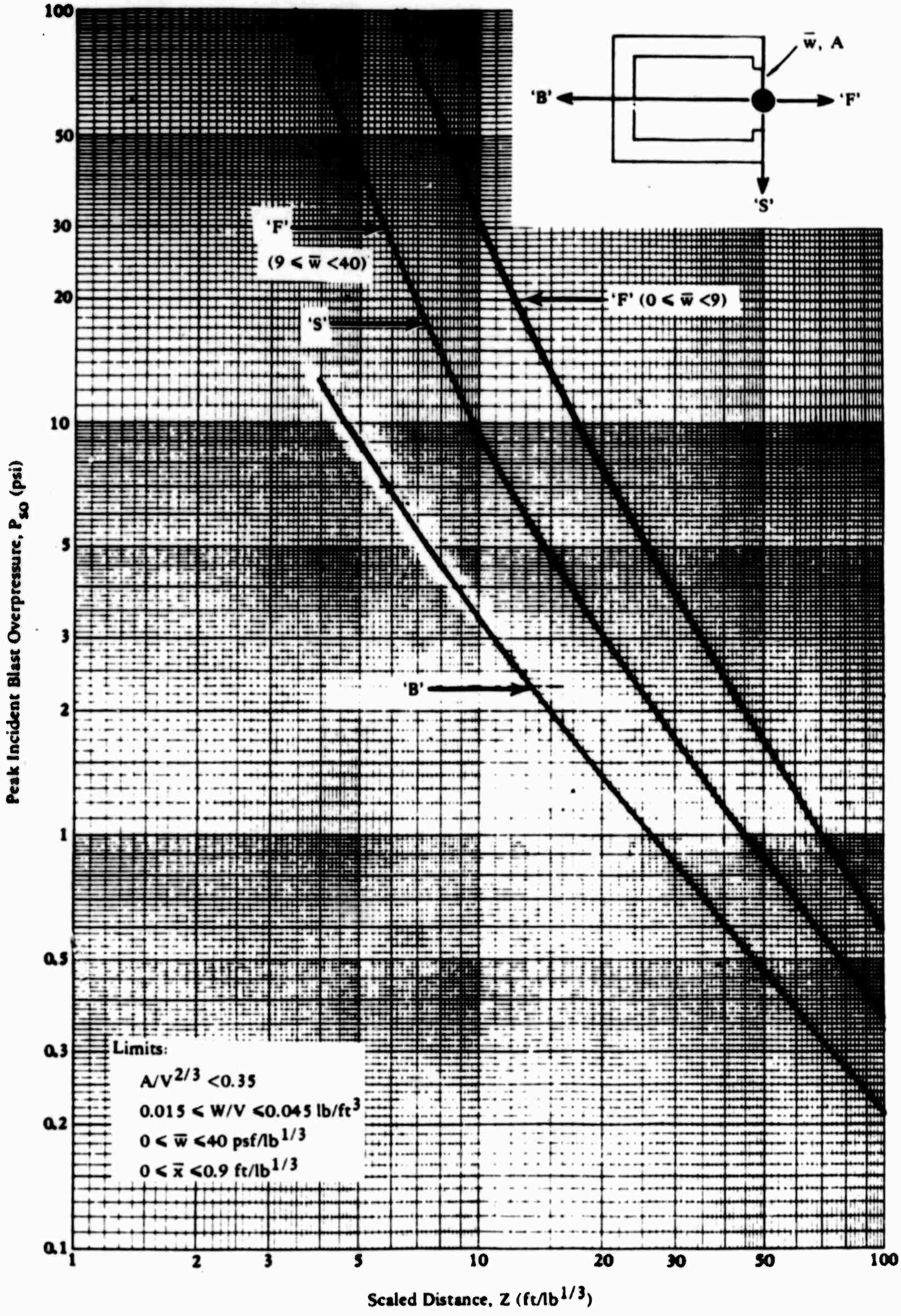


Figure 26. Peak incident design pressure outside NAVFAC MTC.

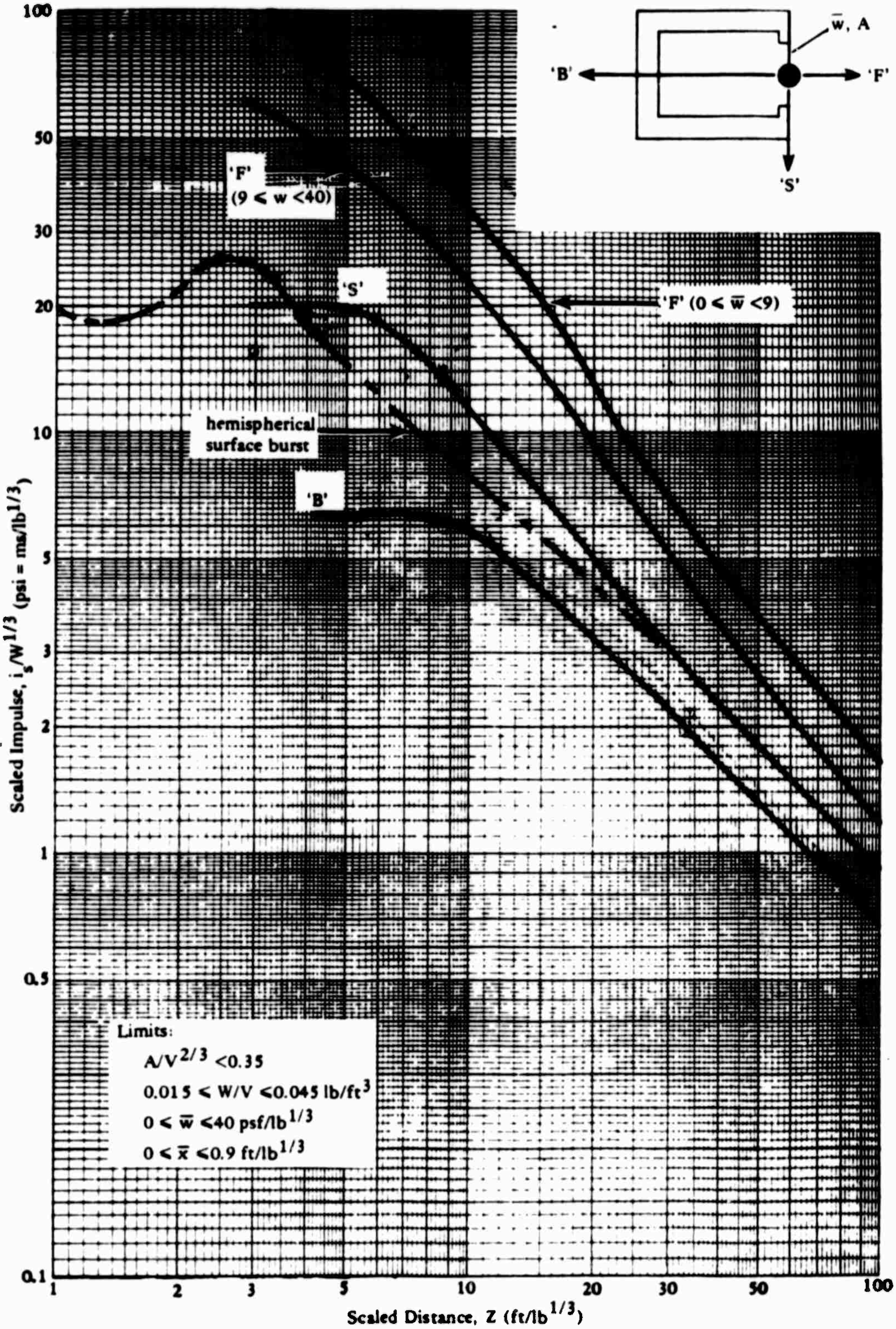


Figure 27. Scaled incident design impulse outside NAVFAC MTC.

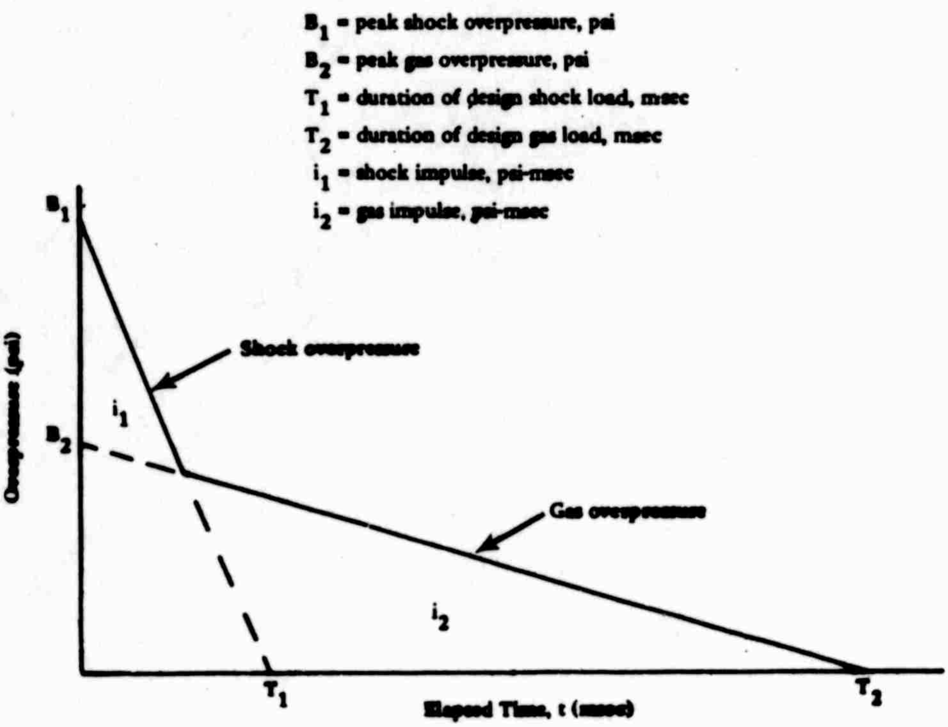


Figure 28. Combined internal design loading for MTC.